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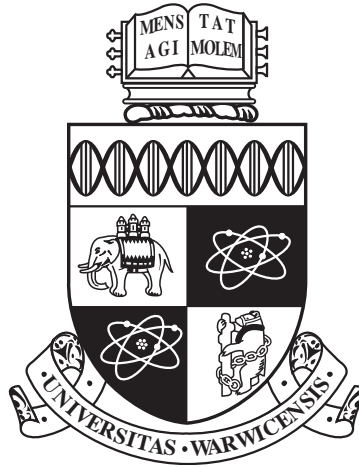
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**Three Essays in International Economics:
Invoicing Currency, Exchange Rate Pass-Through and
Gravity Models with Trade in Intermediate Goods**

by

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A Thesis

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Declaration

This thesis is submitted to the University of Warwick in accordance with the requirements for the degree of Doctor of Philosophy. I declare that this thesis is my own work and has not been submitted for a degree at another university.

Chapter 3 of this thesis contains statistical data from HM Revenue and Customs (HMRC) which is Crown Copyright. The research datasets used may not exactly reproduce HMRC aggregates. The use of HMRC statistical data in this project does not imply the endorsement of HMRC in relation to the interpretation or analysis of the information. For VAT implications of the project that serve HMRC's function, please see the version available on my personal webpage.

Wanyu Chung

July 2014

Abstract

A large proportion of international trade is in intermediate goods. The implications of this empirical regularity, however, have not been exhaustively explored in several aspects. The main objective of the thesis is to fill in the gap by introducing trade in intermediate goods into several strands of literature in international economics. This thesis is a collection of three essays studying the implications of trade in intermediate goods for the degree of exchange rate pass-through (Chapter 2), firms' invoicing currency choice (Chapter 3) and the performance of the gravity models (Chapter 4). In Chapter 2 I present a theoretical framework and show that back-and-forth trade between two countries is associated with low degrees of aggregated exchange rate pass-through. In Chapter 3 I focus instead on firm heterogeneity in the dependence on imported inputs. I show theoretically that exporters more dependent on foreign currency-denominated inputs are more likely to price in the foreign currency. I then test the theoretical prediction using an innovative and unique dataset that covers all UK trade transactions with non-EU partners from HM Revenue and Customs (HMRC). Overall the results strongly support the theoretical prediction. Chapter 4 is a theoretical piece of work showing how the underlying trade structure alters the predictions of the gravity models. I relate gravity equations to labour shares of income. Given that these parameters are industry-specific, the results suggest that it is crucial to take them into account when the main research interest lies in sectoral differences in bilateral trade.

Chapter 1

Introduction

Trade in intermediate goods accounts for as much as two thirds of international trade (WTO International Trade Statistics 2013). The increasing interconnectedness of production processes among countries has also been studied quite extensively by trade economists.¹ For OECD countries, the annual average growth rate of trade in intermediate goods between 1995 and 2006 was around 6.2%, a rate higher than output growth.² With trade in intermediate goods, there is an underlying trade structure in which a country's exports embed imported inputs while imports consist of its exported inputs. This underlying pattern, however, is not captured in most trade studies with models of final goods only.

It was not until recent years that trade in intermediate goods started to attract more scholarly attention. This is perhaps due to an absence of a comprehensive data set decomposing world trade flows by end-use. Another possible explanation is that trade in intermediate goods was simply considered a constant share of total trade, since empirically the share has remained stable over time.

The global financial and economic crisis in 2008, however, revealed the importance of cross-border intermediate input linkages in explaining the widespread declines in world trade. When demand for the final good is ultimately spread out over demand for intermediates in many countries, the transmission of demand shocks during a slowdown may be more rapid and greater for some regions and industries.³ Trade in intermediate goods thus deserves special attention from trade policymakers.

¹In the thesis, trade in intermediate goods is defined broadly as the exchange of inputs, distinct from a narrower definition of vertical specialisation, the production process in which several countries participate in various stages of single production chains. Other related terms include global value chains, vertical specialisation, outsourcing and fragmentation. See Hummels, Ishii and Yi (2001) for the definitions.

²See the OECD policy paper by Miroudot, Lanz and Ragoussis (2009).

³See Bems, Johnson and Yi (2011), for example, for the role of vertical linkages in accounting for the collapse of world trade during the global recession of 2008-2009. Also, Bems, Johnson and Yi (2010) examine the demand spillovers and the elasticity of world trade to GDP in the recession.

This thesis is a collection of three essays studying the implications of trade in intermediate goods for the macroeconomy as well as the performance of the gravity models in explaining bilateral trade flows. Chapter 2 studies theoretically how a back-and-forth trade structure between two countries alters the responses of domestic prices to a change in exchange rates (i.e. the degree of exchange rate pass-through). This chapter is motivated by the debates on how currency denomination in international trade affects the degree of exchange rate pass-through in the new open economy macroeconomic (NOEM) literature.⁴ I introduce trade in intermediate goods into a framework with endogenous currency choice and examine how the use of intermediate goods alters the equilibrium degrees of pass-through. Chapter 3 examines the link between the use of intermediate goods in production and firms' invoicing currency choice. It focuses in particular on firm heterogeneity in the degree of dependence on imported inputs. I also provide empirical evidence on firms' invoicing currency choice from UK customs data. In Chapter 4 I introduce trade in intermediate goods into a model with complete specialisation and monopolistic competition and derive the gravity equations capturing trade in both final goods and intermediate goods. The focus of the paper is to highlight how the underlying trade pattern alters the predictions of the gravity equations. The thesis structure is shown in Figure 1.1.

1.1 Relation to the Literature

There has been a growing interest in the growth and accounting of trade in intermediate goods in the literature.⁵ Campa and Goldberg (1997) report the growing imported input shares in all manufacturing industries in the UK, Canada and the US from 1974 to 1993. Hummels, Ishii and Yi (2001) construct a measure of vertical specialisation (VS) and show that growth in vertical specialisation accounts for 30% of the export growth in 10 OECD countries between 1970 and 1990.⁶ More recent work has started to construct a systematic measure to account for global production sharing. Johnson and Noguera (2012), for example, calculate the value-added contents of exports (VAX ratios) for 94 countries and 57 sectors in 2004. Since these

⁴The NOEM models, pioneered by Obstfeld and Rogoff (1995), have two distinctive features: (i) a general-equilibrium set-up based on microfoundations and (ii) the introduction of nominal rigidities and imperfect competition. See Lane (2001) for a survey study. Also see Bowman and Doyle (2003) for a discussion on currency denomination in the NOEM literature.

⁵Trade in intermediate goods can be assessed using either country input-output tables or the United Nation's Broad Economic Categories (BEC) classification. See Miroudot, Lanz and Ragousis (2009) for the advantages and drawbacks of the two methodologies.

⁶They use OECD input-output database. Vertical specialisation is defined as the production process in which several countries participate in various stages of single production chains. The VS measures of Hummels et al. (2001) capture the imported contents of exports, or equivalently, foreign value-added embodied in a country's gross output of exports.

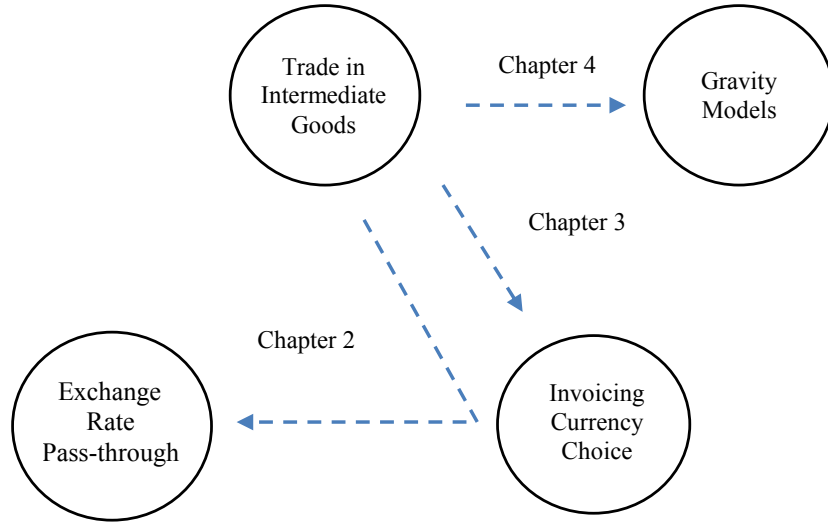


Figure 1.1: Thesis Structure

measures capture the domestic value-added contents of exports, a higher VAX ratio implies less use of imported inputs in producing exporting goods. Chapter 3 is an example of the application of the VAX ratios. I use the VAX ratios at the country and country-industry levels to proxy for the degree of dependence on imported inputs.⁷

Another important feature all the three chapters share is an imperfectly competitive market. Under perfect competition firms have no market power to determine the prices, whereas firms in imperfectly competitive markets are able to practice price discrimination. The earlier literature usually assumed perfect competition and hence the law of one price holds. By moving to imperfectly competitive models this has allowed to assume that the LOOP fails and permitted to better understand issues such as pricing-to-market and market segmentation.⁸ Apart from the price-setting aspect, assuming imperfect competition is also crucial to the discussion of currency denomination as this has allowed to endogenise exporters' currency choice. In both Chapter 2 and 3 firms are assumed to choose an invoicing currency which maximises their profits.

In the trade literature, the assumptions of imperfect competition and product

⁷They use the Global Trade Analysis Project (GTAP) database with input-output tables. The VAX ratios at the country-industry level are not published in the paper.

⁸For the pricing to market (PTM) literature on exchange rate pass-through, see Krugman (1987), Knetter (1989; 1993) and Goldberg and Knetter (1997), among others.

differentiation yield a different motive of trade: economies of scale, rather than differences in technology which generate comparative advantages in the Ricardian model, or in factor endowments in the Heckscher-Ohlin model. If goods are differentiated and production takes place under increasing returns to scale, then even exactly identical countries would trade with one another, and would benefit from opening up to trade.⁹

Below I turn to discuss other related literature for each chapter separately. Chapter 2 belongs to the new open economy macroeconomics (NOEM) literature on incomplete exchange rate pass-through. In the earlier NOEM models such as Obstfeld and Rogoff (1995) and Galí and Monacelli (2005), the LOOP is assumed and therefore exchange rate pass-through is complete. Later studies have attempted to model incomplete pass-through from several perspectives, such as pricing-to-market (e.g. Sutherland, 2005), the existence of a retail sector (e.g. Smets and Wouters, 2002 and Monacelli, 2005) and presence of trade transaction costs (e.g. Corsetti and Dedola, 2005). The main debate, however, has been centered around whether firms choose to pre-set the prices of exports in the producer's currency or the importer's currency (e.g. Betts and Devereux, 1996). Invoicing currency choice directly determines whether domestic prices respond to a change in exchange rates and therefore has strong implications for the degree of exchange rate pass-through. Most earlier studies, however, take invoicing currency choice as exogenous and not until recently did the literature start to model endogenous currency choice (e.g. Devereux, Engel and Storgaard, 2004). Chapter 2 adds new insight into the NOEM literature by introducing trade in intermediate goods into the framework of Devereux, Engel and Storgaard (2004) with endogenous currency choice. The main contribution of this paper is to identify the channels through which back-and-forth trade affects pass-through in an environment of endogenous currency choice.

Chapter 3 is related to an extensive theoretical literature on the determinants of invoicing currency.¹⁰ These determinants include: (i) macroeconomic considerations, such as exchange rate volatility (Devereux et al., 2004) and transaction costs of exchange (Devereux and Shi, 2013); (ii) industry characteristics, such as market competition (Bacchetta and van Wincoop, 2003) and price-sensitivity of demand (Bacchetta and van Wincoop, 2005); (iii) strategic characteristics, such as bargaining between exporters and importers (Goldberg and Tille, 2008). The main contribution of the chapter is to add an alternative but complementary determinant of invoicing currency to the literature, namely firms' use of imported inputs. The

⁹See Krugman (1979; 1980) for the frameworks of monopolistic competition and complete specialisation. It is also worth noting here that imperfect competition is not the only market structure compatible with a gravity model.

¹⁰Early literature with a micro perspective include Baron (1976), Giovannini (1988), Donnenfeld and Zilcha (1991) and Friberg (1998).

model setting in Chapter 3 is based on the framework developed in Chapter 2 but deviates to incorporate firm heterogeneity in the degree of dependence on imported inputs.¹¹

From an empirical perspective, evidence on firm-level invoicing currency choice remains scarce. This is due to limited disaggregated data on invoicing currency. One example is the survey study of Friberg and Wilander (2008) on Swedish exporters' currency considerations. A study that uses similar empirical models to mine is Goldberg and Tille (2011). They document the evidence on strategic interactions from Canadian import transactions.¹² This chapter uses an innovative dataset from UK customs to provide firm-level evidence on the link between the dependence on imported inputs and exporters' currency choice. Another contribution of the paper is to link firm-level characteristics such as firm size (in terms of export shares) and firm experience (in terms of years of exporting) to the choice of invoicing currency.

In addition to the literature studying incomplete pass-through and the determinants of invoicing currency choice, Chapter 2 and 3 also relate to the growing literature on the frequencies of price adjustments. This new literature documents differences in price adjustments for goods invoiced in different currencies (e.g. Floeden and Wilander, 2006; Gopinath, Itskhoki and Rigobon, 2010). My papers share the interest in currency denomination but differ in the consideration of the use of imported inputs. Furthermore, some recent studies have looked into the direct relationship between the use of imported inputs and the degree of pass-through (e.g. Amiti, Itskhoki and Konings, 2014). In contrast to my focus on currency choice, these studies highlight variable markups as the main channel through which imported inputs alter the firm-level degree of exchange rate pass-through to prices.

Chapter 4, distinct from the other two chapters, relates to two strands of the trade literature: trade theories on complete specialisation and monopolistic competition and the gravity models. In the trade literature, a number of studies have incorporated the use and trade of intermediate goods. Ethier (1982) introduces differentiated intermediate goods into Krugman (1979) and assumes homogeneous final goods. Hence all trade is in intermediate goods. My paper has a similar setting based on the Krugman model, but differs in allowing for trade in both intermediate and final goods. Krugman and Venables (1996) develop a model with the use and trade of intermediate goods and discuss the welfare effects of globalisation. In contrast to my interest in distinguishing trade in intermediate goods from final goods, their framework assumes that the composite intermediate good is the same as the composite final good, i.e. an identical elasticity of substitution between varieties

¹¹See the overview of Chapter 3 in Section 1.3 for the detailed comparisons.

¹²They use industry-level variables such as market shares of exporters and transaction sizes to proxy for the bargaining power of exporters and importers.

in intermediate goods and varieties in final goods. My paper distinguishes firms' elasticity of substitution between intermediate goods from consumers' elasticity of substitution between final goods.

Gravity equations for gross trade can be derived from a number of trade models such as Krugman (1979), Eaton and Kortum (2002) and Melitz (2003). Some scholars have also considered the cross-border intermediate input linkages. Noguera (2012), for example, derives an approximation of the gravity equation for value-added trade based on Anderson and van Wincoop (2003). Chapter 4 of the thesis, however, is more closely related to the gravity literature which argues that the economic mass variables (i.e. GDP) in gravity equations fail to be good proxies when trade in intermediate goods are more dominant. Bergstrand and Egger (2010) and Baldwin and Taglioni (2011), for example, show that the standard gravity variables perform well on a huge database consisting a wide range of countries. When testing the standard gravity equation on a subsample of the Factory Asian countries, however, Baldwin and Taglioni (2011) report a relatively poor performance.¹³ The approach in Chapter 4 differs from these studies in the objective of identifying what drives the differences between trade in intermediate goods and final goods from a theoretical point of view. The main contribution of the paper is to relate gravity equations to labour shares of income and show that these parameters should be taken into account in analysing the effects of industry-specific factors on bilateral trade flows.

In the next sections I discuss each chapter's background and provide an overview of the key findings.

1.2 Overview of Chapter 2

Chapter 2 of the thesis, "Back-and-forth Trade, Currency Choice and Endogenous Exchange Rate Pass-through," examines theoretically how trade in intermediate goods between two countries (hence the term back-and-forth trade) affects the aggregated degree of exchange rate pass-through.

1.2.1 Background

Exchange rate pass-through, by definition, is the percentage change in domestic prices resulting from a one-percent change in the nominal exchange rate. From a policy perspective, understanding exchange rate pass-through is critical due to its far-ranging implications for the international transmission of macroeconomic shocks, the effectiveness of monetary policy, as well as the welfare benefits of policy

¹³The Factory Asian countries include Japan, Indonesia, Korea, Malaysia, Philippines, Thailand and Taiwan.

coordination. A scholarly consensus is that the degree of exchange rate pass-through to import prices (and accordingly consumer prices) is less than complete and many countries have experienced dramatic declines in the degree of pass-through.¹⁴

A great deal of theoretical effort has been taken to explain the causes and the underlying determinants of incomplete pass-through. A non-exclusive list includes: price stickiness, pricing to market behaviour of firms, transportation costs, and the existence of non-tradable goods. Following some pioneering microeconomic studies, firms' choice of invoicing currency also comes into the picture as another significant variable determining the degree of pass-through.¹⁵ Whether exporters tend to choose local currency pricing (LCP) or producer currency pricing (PCP) has been one of the most debated issues in the new open economy macroeconomics (NOEM) literature. This is because these two extreme cases imply opposite exchange rate pass-through behaviours: given price stickiness if all home imports are priced in the foreign currency, there is full pass-through. That is, domestic prices respond one-to-one to a change in exchange rates. On the contrary, if all home imports are priced in the home currency, there is zero pass-through since prices do not respond to a change in exchange rates.¹⁶ It was not until recently, however, that firms' invoicing currency choice was considered endogenous in the models.¹⁷

Given the observation that trade in intermediate goods is empirically evident and not taken into account in the existing macroeconomic models, this paper attempts to introduce trade in intermediate goods into an NOEM model setting with endogenous currency choice. The main focus of the paper is on the implications of (aggregated) input currency denomination for the (aggregated) degree of pass-through.

1.2.2 Preview of the Results

The model setting is based on Devereux, Engel and Storgaard (2004) with price stickiness and endogenous currency choice. I introduce a simple two-way exchange of intermediate goods between home and foreign into a general equilibrium set-up. Profit-maximising firms are assumed to preset prices in either their own home currency or the foreign currency for their final goods one period in advance, taking into account the currency used for their imported inputs. Input currency denomination is assumed exogenous with a certain share of firms facing home currency-denominated

¹⁴See Campa and Goldberg (2005) and Gagnon and Ihrig (2004) for empirical evidence for a sample of industrialised countries.

¹⁵For example, Giovannini (1988) and Friberg (1998).

¹⁶Betts and Devereux (1996) are the first who introduce LCP, as opposed to the assumption of PCP in the Redux model (Obstfeld and Rogoff, 1995), the first benchmark model in the NOEM literature. Bailliu and Fujii (2004) argue that in reality, these two cases coexist.

¹⁷See, for example, Devereux, Engel and Storgaard (2004) and Gopinath, Itskhoki and Rigobon (2010).

inputs whereas the rest faces foreign currency-denominated inputs.¹⁸ One justification for this assumption is the example of oil, which is mainly denominated in US dollars. Another interpretation is that this captures firms that do not use imported inputs in reality as their currency behaviour is identical to firms that use home currency-denominated inputs from the model's perspective.

The general equilibrium model yields two main results. Firstly, at an aggregated level the more use of foreign currency-denominated inputs, the lower the pass-through. I identify two channels. The first direct channel is that a change in input currency denomination leads to a change in firm composition. When there are more firms facing foreign currency-denominated inputs, for example, lower pass-through is observed since firms facing foreign currency-denominated inputs are more likely to use the same currency (LCP) for exports. The second channel is an indirect one through a two-way relationship between exchange rate volatility and pass-through: exchange rate volatility affects firms' currency choice and consequently the degree of pass-through. The degree of pass-through, in turn, affects the distribution and volatility of exchange rates. Overall, the results suggest that back-and-forth trade is associated with lower exchange rate pass-through. Secondly, I find a negative relationship between the elasticity of substitution between home and foreign intermediate goods and the equilibrium pass-through. This result relates to the empirical evidence in the existing pass-through literature that higher pass-through occurs for more homogenous product sectors (with lower elasticity of substitution).¹⁹

1.3 Overview of Chapter 3

Chapter 3 of the thesis, "Imported Inputs and Invoicing Currency Choice: Theory and Evidence from UK Transaction Data," is my job market paper. The paper has both theoretical and empirical parts. In this paper I investigate firm heterogeneity in terms of exporters' dependence on imported inputs and how this affects their choice of invoicing currency.

1.3.1 Background

Invoicing currency choice has real effects on macroeconomy. For example, it affects how trade balances respond to a change in exchange rates in the short run. How do exporters choose an invoicing currency? Until recently little was known beyond a number of broad stylised facts, based mainly on aggregated data. Among those facts, trade in primary products is mostly denominated in US dollars, while trade

¹⁸I later relax this assumption in an appendix.

¹⁹See, for example, Gopinath, Itskhoki and Rigobon (2010).

between developing and industrialized countries is predominantly invoiced in the industrialized country's currency. It is also acknowledged that inflationary currencies are less likely to be used in foreign trade.²⁰

The limitation of the existing literature is perhaps due to the limited availability of disaggregated data on invoicing currency. This paper aims at filling in the empirical gap by providing some stylized facts from an innovative dataset that covers all UK trade transactions with non-EU partners from HM Revenue and Customs (HMRC). The dataset is not publicly available.

Based on the theoretical results in Chapter 2, *at an aggregated level* input currency denomination has strong implications for firms' invoicing currency choice. The main research question this paper addresses is *at the firm level* how exporters' dependence on imported inputs affects their invoicing currency choice. This chapter is the first to look at the dependence on imported inputs (at the firm-level) as a theoretical determinant of exporters' invoicing currency and provide firm-level evidence that supports the theoretical predictions.

1.3.2 Preview of the Results

The theoretical part of the paper is mainly based on the model presented in Section 2.2 of Chapter 2 and the cost structure is based on Halpern, Koren and Szeidl (2011). It is a simple partial-equilibrium framework with price stickiness. The key difference from Chapter 2 is firm heterogeneity. In this paper, firms differ in their productivity in using imported inputs, hence their dependences on imported inputs. Table 1.1 provides a comparison of the model settings.

The model yields two testable hypotheses. Firstly, exporters more dependent on foreign currency-denominated inputs are more likely to price in the foreign currency. The intuition is that pricing in the foreign currency provides a natural hedge against exchange rate uncertainty. Secondly, exchange rate volatility makes the firm prefer its own currency (consistent with Devereux, Engel and Storgaard, 2004).

In the empirical part of the paper I first document some stylized facts of currency denomination for UK trade. I focus on the dataset that covers all trade transactions with non-EU countries in 2011. The dataset has 2.54 million transactions for exports and 7.31 millions for imports. I then match import and export data to relate exporters' invoicing currency choice to import behaviour. The econometric results strongly support the theoretical predictions.

Other findings shed some light on relating currency choice to firm characteristics. For instance, larger UK exporters are less inclined to use their domestic currency.

²⁰See, for example, Grassman (1973), McKinnon (1979) and Tavlas (1991). Also, see Kamps (2006) for a discussion.

Table 1.1: Model Settings in Chapter 2 and Chapter 3

	Chapter 2	Chapter 3
Focus of Analysis	Aggregated degree of pass-through	Firm heterogeneity in currency choice
Model	General-equilibrium	Partial-equilibrium
Demand	CES	CES
Baseline Model	Devereux et al. (2004)	Chapter 2 and Halpern et al. (2011)
Firms	Differ in input currency denomination (2 Types)	Differ in dependence on imported inputs
Input Currency Denomination	Exogenous: some firms PCP others LCP	Exogenous: All PCP
Currency Choice	PCP or LCP	PCP or LCP
Extension in Appendices	Endogenous input currency choice	Allowing for a third vehicle currency

In contrast, all else being equal experienced firms (trading for more than five years in exporting markets) are more inclined to use pound sterling for exports.

These results have strong policy implications. Empirical evidence has shown that in the UK pass-through to domestic prices exhibits significant heterogeneity across industries. The manufacturing and raw materials sectors, for example, have much higher pass-through than the energy sector (Muntaz, Oomen and Wang, 2006). Therefore identifying what determines currency choice and whether firm characteristics play a role becomes crucial to fully understand the cause of the variation.

1.4 Overview of Chapter 4

Chapter 4 of the thesis, "Gravity with Trade in Intermediate Goods," asks how trade in intermediate goods alters the predictions of the gravity models.

1.4.1 Background

The gravity model of trade estimates bilateral trade flows based on the economic sizes and distance between two countries, as well as other variables that affect trade costs. The model has been an empirical success in explaining the effects of distance-related factors on bilateral trade flows. These include national borders, tariff and non-tariff barriers, trade costs, as well as non-economic factors such as cultural and language differences.

However few studies in the existing gravity literature have incorporated trade in intermediate goods. Given the rise of global production sharing, it is natural to ask what drives up trade in intermediate goods and how it differs from trade in final goods. This paper therefore aims at introducing trade in intermediate goods into a trade model compatible with the gravity equations to analyse to what extent the use and trade in intermediate goods matters to the predictions of the standard gravity models with final goods trade only.

1.4.2 Preview of the Results

I start with an accounting exercise showing that even without trade in intermediate goods, gravity models over-predict trade volume with the presence of (domestically produced) intermediate goods. More interestingly, trade in intermediate goods helps mitigate such effect. I also show that the standard frictionless gravity model predicts a lower volume of trade for smaller importing countries.

I then build a general equilibrium model based on Krugman (1979) with complete specialisation and monopolistic competition. The first finding is that there are gains from trade for both trade in intermediate goods and final goods. The degree depends on the elasticities of substitution and the production function parameters. I then derive gravity equations for trade in both types of goods separately.

The model results show that labour shares of income enter the two gravity equations with different signs. More interestingly, the weighted averages on labour shares of income in the importing country and the exporting country also enter the equations with different signs. This is because in the model, a higher labour share of income in the exporting country implies a larger intermediate goods sector (which uses labour only). The same parameter for the importing country, however, captures higher income spent on final goods. Given that the parameter is industry-specific, the implication of these results is that it is crucial to take it into account when the main research interest is the effects of industry-specific factors on bilateral trade flows.

Chapter 2

Back-and-forth Trade, Currency Choice and Endogenous Exchange Rate Pass-through

2.1 Introduction

It has been widely acknowledged that the nature of international trade has evolved toward more intra-industry trade, in contrast to the classical theories based on the concept of comparative advantage.²¹ East Asian economies, in particular, have not only experienced the expansion of intra-regional trade in final goods, but also increasing intra-industry trade of intermediate goods such as machinery parts and components (i.e. back-and-forth trade). By definition, back-and-forth trade exists when countries involve in any exchange in intermediate goods.²² With back-and-forth trade, exports consist of imported inputs and imports consist of exported inputs. Therefore it is important to take international trade interdependence into account when analysing trade structure.

Such phenomena, albeit empirically evident, are not yet well explored at a more aggregate macroeconomic level in terms of their implications for policy design.²³

²¹Intra-industry trade refers to the exchange of (intermediate or final) products belonging to the same industry. It has been divided into two sub-concepts: horizontally differentiated products (i.e. with similar quality and price) and vertically differentiated ones.

²²In this paper, back-and-forth trade is a broad concept distinct from a narrower definition of vertical specialisation, the production process in which several countries participate in various stages of single production chains. See Hummels, Ishii and Yi (2001) for the definition. Other labels equivalent to vertical specialisation may be identified in the literature, e.g. slicing up the value chain, outsourcing, fragmentation and production network.

²³For example, Ando and Kimura (2003) confirm the importance of the back-and-forth trade of machinery parts and components in East Asia. Haddad (2007) provides evidence on the increasing trend of vertical specialisation. The definitions of vertical specialisation in these two papers are consistent with Hummels et al. (2001). Also, the IMF's Asia and Pacific Regional Economic Outlook 2007, reports a rise in Asian intra-industry trade, identifying a 60-65 per cent share of the

Put differently, although much scholarly attention has been given to the nature and the explanation of intra-industry trade, how this interdependence impacts macroeconomic performances, in particular exchange rate pass-through to domestic price levels, remains unexplained.²⁴ This observation motivates the research idea to introduce trade interconnectedness into the new open economy macroeconomics (NOEM) literature.

The understanding of exchange rate pass-through is believed to be crucial due to its strong implications for the international transmission of macroeconomic shocks, the effectiveness of monetary policy, as well as the welfare benefits of policy coordination. A scholarly consensus is that the degree of exchange rate pass-through to import prices (and accordingly consumer prices) is less than complete, and many countries have experienced dramatic declines in the degree of pass-through since 1990s.²⁵ To understand the underlying determinants of incomplete pass-through, most theoretical work in the NOEM literature has focused on invoicing currency choice, i.e. different pricing behaviour of exporters in different markets. One of the early debates is whether exporters choose local currency pricing (LCP) or producer currency pricing (PCP), since these two extreme cases imply opposite exchange rate pass-through behaviour (i.e. zero pass-through in the case of LCP and full pass-through in PCP).²⁶ These debates have brought about later studies that regard currency choice as endogenous in the models, e.g. Devereux, Engel and Storgaard (2004; hereafter DES).²⁷

This paper belongs to the NOEM literature and the model setting is based on DES (2004), with price and wage stickiness. I introduce a simple two-way exchange of intermediate goods between home and foreign countries into a general equilibrium set-up where firms choose their invoicing currency (for final goods) endogenously. The share of inputs denominated in the foreign currency is assumed exogenous. One

intermediate goods in trade flows into emerging East Asian countries.

²⁴One of the few exceptions is Ghosh (2009) who hypothesizes that production sharing is one of the underlying factors of the empirical decline of pass-through. He uses a partial equilibrium model and focuses on the incomplete pass-through of intermediate goods due to exporters' pricing to market (PTM) behaviour, rather than currency of invoicing.

²⁵See Campa and Goldberg (2005) for an empirical examination of pass-through to import prices for 25 OECD countries, and Gagnon and Ihrig (2004), for pass-through to consumer prices for a sample of industrialised countries over the period 1971-2003.

²⁶Betts and Devereux (1996) are the first who introduce LCP to capture the idea of PTM in a general-equilibrium approach and this draws a distinct comparison with the original assumption of PCP in the Redux model (Obstfeld and Rogoff, 1995), the first benchmark model in the NOEM literature. Bailliu and Fujii (2004) argue that in reality, these two cases coexist. On a theoretical front, Corsetti and Pesenti (2001, 2005), for example, build a model assuming that firms are able to react to a fraction of exchange rate movements, and therefore PCP and LCP become two special cases.

²⁷Another example is Corsetti and Pesenti (2004). They model incomplete pass-through endogenously by assuming that firms can decide the degree of pass-through to import prices prior to the realisation of the exchange rates.

justification for this assumption is the example of oil, which is mainly denominated in US dollars.²⁸ This assumption therefore distinguishes two types of firms: one facing foreign inputs denominated in the foreign currency (foreign PCP, hereafter type P firms) and the other facing foreign inputs denominated in the home currency (foreign LCP, hereafter type L firms). Firms are assumed to preset prices and currency for their final goods one period in advance, taking into account the currency used for their imported inputs.

The main contribution of this paper is to relate input currency denomination with firms' invoicing currency choice for final goods and the endogenously determined exchange rate pass-through (to consumer prices). The analysis in this paper proceeds in three stages. In the first stage, I show how optimal currency choice is conducted for profit-maximising firms in pricing their final goods. In a partial equilibrium setting, I take as given the distribution of exchange rates, market demand and prices of other firms. Up to a second order approximation, the optimal decision rules can be established that firms simply take into account the volatility of exchange rates and the covariance of the exchange rate with the marginal costs.²⁹ In the second stage, a NOEM framework with back-and-forth trade is presented, taking firms' currency choice as given. In the third stage, by combining the previous two, the degree of pass-through is then endogenously determined by the measures of firms that choose PCP/LCP for the final goods. It is then possible to discuss how input currency denomination affects firms' currency choice and the degree of exchange rate pass-through in a general equilibrium set-up.

The first key result answers the question how back-and-forth trade affects firms' invoicing currency choice. In the first stage of the analysis I develop firms' decision rules and compare them with the case when there is no imported inputs as in DES (2004). In a partial equilibrium set-up I show that the use of imported inputs creates a wedge between the two types of firms in a way that type P firms have more incentive to use LCP whereas type L firms have more incentive to use PCP, all else being equal. In other words, firms tend to use the same currency of their imported inputs for exports. Moreover, the higher the expenditure share on imported inputs, the larger the wedge between the two types of firms.

The second key result answers the question how input currency denomination affects firms' invoicing currency choice and accordingly the degree of exchange rate pass-through. Overall the result shows that the more use of foreign currency-denominated inputs, the lower the pass-through. Two channel are identified from

²⁸I later relax this assumption and present the results in Appendix 2.D.

²⁹The first paper that stresses the role the currency of denomination of export prices plays in determining the correlations of prices and the exchange rate is perhaps Giovannini (1988). In his paper, whether choosing home or foreign currency is optimal depends on whether the profit function is convex or concave of the exchange rate, respectively.

the general equilibrium results. The first channel is a direct one that a change in input currency denomination leads to a change in firm composition. An exogenous increase in the share of inputs denominated in the foreign currency, for example, results in more type P firms in the home country. Hence lower pass-through is observed. The second channel is an indirect one through a two-way relationship between exchange rate volatility and pass-through.³⁰ A change in input currency denomination (firm composition) first results in a shift in currency choice behaviour (the direct channel). This alters the degree of exchange rate pass-through and then the exchange rate distribution. Exchange rate distribution, in turn, affects firms' decision rules and generates an endogenously determined new level of pass-through.

The equilibrium results also suggest a link between the elasticity of substitution between home and foreign intermediate goods with the degree of pass-through. By comparing the equilibrium conditions I find a negative relationship between the elasticity of substitution and the equilibrium pass-through. This result relates to the empirical evidence in the existing pass-through literature that higher pass-through occurs for more homogenous product sectors (with lower elasticity of substitution).³¹

The paper is structured as follows. The next section sets out the model assumptions, followed by the first-stage partial equilibrium analysis, in which firms' decision rules are established. Section 2.3 provides the settings of the general equilibrium framework. Section 2.4 offers the equilibrium conditions as well as the key results. Section 2.5 concludes.

2.2 Back-and-forth Trade and Currency Choice

In this section, firms' currency choice is examined in a partial equilibrium setting. There are two countries trading both intermediate and final goods. Firms in both countries use imported intermediate goods as inputs for the production of final goods. Figure 2.1 demonstrates the trade structure.

2.2.1 Demand and Production

In the home country, the export sector contains a unit interval of firms indexed by i and is monopolistic competitive. Each firm sells a differentiated intermediate good and a differentiated final good to the foreign country and faces CES demand

³⁰This two-way relationship, firstly identified in DES (2004), is the key mechanism of endogenous pass-through. Exchange rate volatility affects firms' invoicing behaviour, and accordingly the degree of pass-through. The degree of aggregate pass-through, in turn, affects the distribution and volatility of exchange rates.

³¹See, for example, Gopinath, Itskhoki and Rigobon (2010). They examine how invoicing currency choice affects firms' price adjustments and accordingly endogenous exchange rate pass-through. They document higher frequencies of price adjustments and high pass-through for homogenous goods.

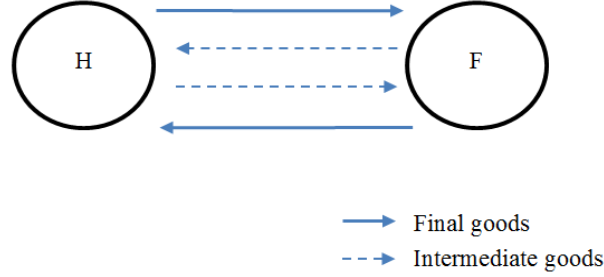


Figure 2.1: A Two-country Back-and-forth Trade Structure

functions for the intermediate and final good, respectively:

$$Y_X^d(q^i) = \left(\frac{q^i}{Q_{hf}^*} \right)^{-\lambda_X} \left(\frac{Q_{hf}^*}{Q^*} \right)^{-\theta_X} X^*, \quad (2.1)$$

$$Y^d(p^i) = \left(\frac{p^i}{P_{hf}^*} \right)^{-\lambda} \left(\frac{P_{hf}^*}{P^*} \right)^{-\theta} C^*, \quad (2.2)$$

where the X subscripts denote variables of intermediate goods and q^i is the price of the intermediate good i . Q_{hf}^* is the price index for all home intermediate goods sold in the foreign country, which is taken as given by the firm. Q^* is the intermediate goods price index in the foreign country. Also, p^i is the price the foreign consumer pays for home final good i , P_{hf}^* is the price index for all home final goods sold in the foreign country, and P^* is the foreign consumer price index. Let all prices be denominated in the foreign currency here. X^* and C^* are foreign demand shifters that are independent of prices. Parameters λ and λ_X are the price elasticities of demand facing any firm i with $\lambda, \lambda_X > 1$. Parameters θ and θ_X are the foreign price elasticities of demand for domestic goods.

Production of intermediate goods uses only (differentiated) labour. Labour is assumed immobile across countries. To maintain symmetry, assume that any firm uses workers of each type. Therefore, in producing intermediate good, each firm i in the home country follows a production function:

$$Y_X^i = \left[\left(\frac{1}{n} \right)^{\frac{1}{\omega}} \int_0^n (L_k^i)^{1-\frac{1}{\omega}} dk \right]^{\frac{\omega}{\omega-1}} \equiv L^i, \quad (2.3)$$

where ω is the elasticity of demand between types of labour. Given a distribution of

wages W_k , the marginal cost of producing intermediate goods is given by $MC_X = \left(\frac{1}{n} \int_0^n (W_k)^{1-\omega} dk \right)^{\frac{1}{1-\omega}} \equiv W$.

In producing final goods, each firm i uses labour together with both imported and domestically produced intermediate goods, following a Cobb-Douglas production technology:

$$Y^i = A (L^i)^{1-\delta-\gamma} (X_h^i)^\delta (X_{fh}^i)^\gamma, \quad (2.4)$$

where X_h is the amount of domestically produced intermediate goods used in the production, and X_{fh} is the amount of (imported) intermediate goods used in the production. A is a constant productivity term.³² Firms are divided into two types: type P firms use imported inputs denominated in foreign currency (i.e. PCP by foreign exporters) and type L firms use imported inputs denominated in home currency (i.e. LCP by foreign exporters). Given the production function, marginal costs for type P firms and type L firms, respectively, are given by:

$$MC(q^*) = (MC_X)^{1-\gamma} (S \cdot q_{fh}^{i*})^\gamma, \quad (2.5)$$

$$MC(q) = (MC_X)^{1-\gamma} (q_{fh}^i)^\gamma, \quad (2.6)$$

where S is the exchange rate, or home currency price of foreign currency; q_{fh}^{i*} (denominated in the foreign currency) and q_{fh}^i (denominated in the home currency) are the prices facing type P and type L firms, respectively.

2.2.2 PCP versus LCP

Input currency denomination is assumed exogenous in the main analysis.³³ With this assumption we have an exogenous share of firms facing PCP/LCP inputs.

In this section I develop firms' pricing and currency choice rules for their final goods. Firms evaluate profits and set optimal prices one period ahead, using the exogenous discount factor κ . If a firm uses its own currency (PCP), then the expected discounted profit is:

$$E\Pi^{PCP} = E \left[\kappa (p^i - MC) \left(\frac{p^i}{S P_{hf}^*} \right)^{-\lambda} \left(\frac{P_{hf}^*}{P^*} \right)^{-\theta} C^* \right]. \quad (2.7)$$

If a firm uses the foreign currency (LCP), then the expected discounted profit

³²Note that home demand for imported intermediate goods is independent of domestic prices, i.e. foreign firms face a CES demand curve for their intermediate exports taking the form as equation (2.1).

³³See Appendix 2.D for the extension case with endogenous currency choice for intermediate goods. Since the production of intermediate goods uses labour only, the decision rule is exactly the same as the case with no foreign inputs ($\gamma = 0$). The optimal pricing for intermediate goods follows similar forms as pricing for final goods.

is:

$$E\Pi^{LCP} = E \left[\kappa (Sp^{i*} - MC) \left(\frac{p^{i*}}{P_{hf}^*} \right)^{-\lambda} \left(\frac{P_{hf}^*}{P^*} \right)^{-\theta} C^* \right]. \quad (2.8)$$

where marginal costs MC are denominated in the home currency.³⁴

The optimal prices which maximise the expected discounted profits, under PCP and LCP, respectively, can be shown as:

$$p^i = \frac{\lambda}{\lambda - 1} \cdot \frac{E(MC \cdot S^\lambda \Omega)}{E(S^\lambda \Omega)}, \quad (2.9)$$

$$p^{i*} = \frac{\lambda}{\lambda - 1} \cdot \frac{E(MC \cdot \Omega)}{E(S\Omega)}, \quad (2.10)$$

where $\Omega = \kappa P_{hf}^{*(\lambda-\theta)} P^{*\theta} C^*$.

Using the equations of prices and marginal costs, I take a second order approximation of the two expected profit functions and establish firms' decision rules.

Proposition 1 *Type P firms (i.e. firms using foreign PCP inputs) choose PCP for their final goods if:*

$$\left(\frac{1}{2} - \gamma \right) \text{var}(s) - (1 - \gamma) \text{cov}(s, w) > 0.$$

Type L firms (i.e. firms using foreign LCP inputs) choose PCP for their final goods if:

$$\frac{1}{2} \text{var}(s) - (1 - \gamma) \text{cov}(s, w) > 0,$$

where $s = \ln S$ and $w = \ln W$.³⁵

Proof. See Appendix 2.A. ■

Note that the case of $\gamma = 0$ captures the model of DES (2004). Proposition 1 says that all else being equal exchange rate volatility, captured by high $\text{var}(\ln S)$, makes the firm prefer PCP. In contrast, the covariance between exchange rates and the home wage makes the firm prefer LCP. Below I discuss the two effects in turn.

The effect of exchange rate volatility enters the decision rule through the firm's consideration of expected revenues. When the firm chooses PCP, the price is stable whereas the quantity (foreign demand) is subject to exchange rate uncertainty. On the other hand, when the firm chooses LCP, the quantity is stable whereas the price is subject to exchange rate uncertainty. The firm therefore faces a trade-off between stabilising price and stabilising quantity. The curvature of revenue

³⁴Note here that the expectation takes place in period $t - 1$ when firms set its price for period t . The time subscripts are omitted here for the simplicity of notations.

³⁵Note that prices of foreign inputs do not appear in the decision rules because they are pre-set at time $t - 1$.

functions matters for the optimal currency choice. Technically, the expected revenue function under PCP is convex in the exchange rate and linear under LCP. Holding all other variables constant, an increase in the exchange rate variance increases expected revenues under PCP relative to LCP. This channel therefore gives firms an incentive to choose PCP.

The second channel is through the uncertainty of marginal costs. A positive covariance between the exchange rate and marginal cost increases the expected total costs under PCP. Take an exchange rate depreciation (higher S), for example, under PCP firms' demand is higher precisely when the cost of production (home wage) is higher. This leads to higher expected total costs. Under LCP, however, demand is independent of the exchange rate, holding other variables constant. This channel therefore gives firms an incentive to choose LCP.

The decision rules for foreign firms are entirely analogous, given that they also face the same CES demands and production technology.

Corollary to Proposition 1 *Foreign type P firms (i.e. firms using foreign PCP inputs) choose PCP for their final goods if:*

$$\left(\frac{1}{2} - \gamma\right) \text{var}(s) + (1 - \gamma) \text{cov}(s, w^*) > 0.$$

Foreign type L firms (i.e. firms using foreign LCP inputs) choose PCP for their final goods if:

$$\frac{1}{2} \text{var}(s) + (1 - \gamma) \text{cov}(s, w^*) > 0,$$

In the following discussion, I turn to examine graphically how firms using different currency-denominated inputs differ in their currency choice behaviour. Figure 2.2 captures firms' decision rules developed in Proposition 1. These figures illustrate how input currency denomination affects firms' currency choice. Figure 2.2(a) shows the case when firms do not use any imported inputs ($\gamma = 0$). High exchange rate volatility gives firms an incentive to choose PCP whereas high covariance between exchange rates and wage gives firms an incentive to choose LCP.

Figure 2.2(b) shows the decision rules with the use of imported inputs. The threshold line becomes flatter for firms that use PCP inputs (type P) and steeper for firms that use LCP inputs (LCP). This suggests that input currency denomination has a strong implication for firms' currency choice. Given any level of exchange rate volatility the use of imported inputs makes type P firms more likely to choose LCP and type L firms more likely to choose PCP, compared to the initial case with no imported inputs ($\gamma = 0$).

Overall, the use of imported inputs makes firms more likely to use the same

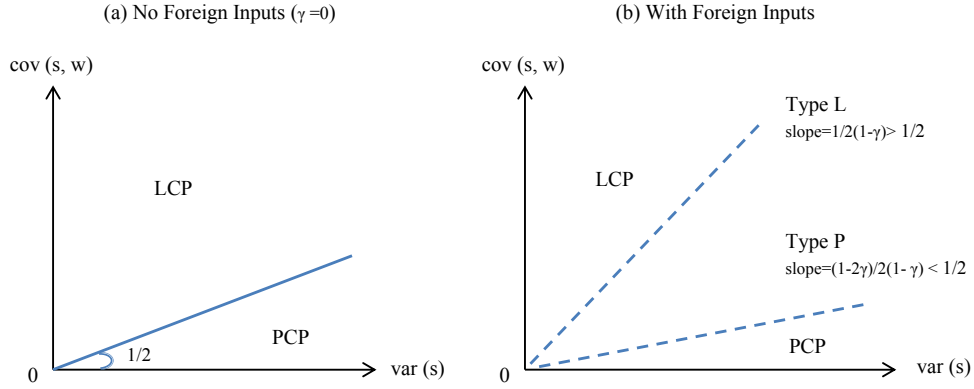


Figure 2.2: Decision Rules for Firms' Invoicing Currency Choice

currency of their imported inputs for exports. The intuition behind this result is that pricing in the foreign currency provides a natural hedge for firms that use foreign currency-denominated inputs. It can also be shown that when production requires higher share of foreign inputs (higher γ), the wedge between type P and type L firms increases.³⁶

2.3 The General Equilibrium Model

The model presented in this section, as the second stage of the analysis, takes as given the measures of firms' currency choices. The world contains a unit interval $[0, 1]$ of firms (households), with the fraction n in Home and $1 - n$ in Foreign.

2.3.1 Preferences and Market Structure

The representative household k maximises the following expected utility:

$$U_t^k = E_t \left(\sum_{s=t}^{\infty} \beta^{s-t} \frac{1}{1-\rho} (C_s^k)^{1-\rho} + \chi \ln \left(\frac{M_s^k}{P_s} \right) - \eta L_s^k \right), \quad (2.11)$$

where $0 < \beta < 1$ and $\rho > 0$.³⁷ $\frac{M}{P}$ is domestic real balance, and L is the labour supply. C is a consumption index and can be decomposed into the consumption of

³⁶The slope for type P firms, $1 - 1/2(1 - \gamma)$, is decreasing in γ . The slope for type L firms, $1/2(1 - \gamma)$, is increasing in γ .

³⁷The elasticity of intertemporal substitution is $1/\rho$.

home and foreign composites:

$$C^k = \left[n^{\frac{1}{\theta}} \left(c_h^k \right)^{\frac{\theta-1}{\theta}} + (1-n)^{\frac{1}{\theta}} \left(c_{fh}^k \right)^{\frac{\theta-1}{\theta}} \right]^{\frac{\theta}{\theta-1}}, \quad (2.12)$$

where θ is the elasticity of substitution between composites. Home and foreign composites are given by:

$$c_h^k = \left[n^{\frac{-1}{\lambda}} \int_0^n \left(c_h^{k,i} \right)^{\frac{\lambda-1}{\lambda}} di \right]^{\frac{\lambda}{\lambda-1}}, \quad (2.13)$$

$$c_{fh}^k = \left[(1-n)^{\frac{-1}{\lambda}} \int_n^1 \left(c_{fh}^{k,i} \right)^{\frac{\lambda-1}{\lambda}} di \right]^{\frac{\lambda}{\lambda-1}}, \quad (2.14)$$

where λ is the elasticity of substitution between individual goods.

Household k has the following budget constraint:

$$P_t C_t^k + M_t^k + B_t^k + \sum \kappa_{t+1} x_{t+1}^k = W_t L_t^k + \Pi_t^k + (1+r_t) B_{t-1}^k + M_{t-1}^k + T_t^k + x_t^k. \quad (2.15)$$

The household consumes goods, accumulates money balances, purchases international bonds (B^k) and state-contingent domestic bonds (x^k). Income is received from wage income, profits from home firms, interests earned on international bonds, money held over from last period, transfers from the government and state-contingent domestic payouts from other home residents. They choose consumption, wage rates (given their individual monopoly power over their differentiated labour), bonds and money balances to maximise utility.

In this setting, I assume incomplete international risk sharing. Consumers can trade abroad only in non-contingent nominal bonds. Within the domestic economy, however, I assume full risk sharing across households. This eliminates the specific uncertainty in wage income across types of households.

The domestic price index is given by:

$$P_t = \left[n P_{ht}^{1-\theta} + (1-n) P_{fht}^{1-\theta} \right]^{\frac{1}{1-\theta}}, \quad (2.16)$$

where P_h and P_{fh} represent the price index of domestic goods and foreign goods sold in home country, respectively:

$$P_{ht} = \left[\frac{1}{n} \int_0^{\bar{z}^* n} \left(p_{ht}^i(q^*) \right)^{1-\lambda} di + \frac{1}{n} \int_{\bar{z}^* n}^n \left(p_{ht}^i(q) \right)^{1-\lambda} di \right]^{\frac{1}{1-\lambda}}, \quad (2.17)$$

$$P_{fht} = \left[\begin{aligned} & \frac{1}{1-n} \int_n^{n+v^*\bar{z}(1-n)} \left(S_t \cdot p_{fht}^{i*}(q) \right)^{1-\lambda} di \\ & + \frac{1}{1-n} \int_{n+v^*\bar{z}(1-n)}^{n+\bar{z}(1-n)} \left(p_{fht}^i(q) \right)^{1-\lambda} di \\ & + \frac{1}{1-n} \int_{n+\bar{z}(1-n)}^{n+\bar{z}(1-n)+u^*(1-\bar{z})(1-n)} \left(S_t \cdot p_{fht}^{i*}(q^*) \right)^{1-\lambda} di \\ & + \frac{1}{1-n} \int_{n+\bar{z}(1-n)+u^*(1-\bar{z})(1-n)}^1 \left(p_{fht}^i(q^*) \right)^{1-\lambda} di \end{aligned} \right]^{\frac{1}{1-\lambda}}, \quad (2.18)$$

where \bar{z} (\bar{z}^*) is the fraction of domestic (foreign) firms that engage in PCP for intermediate goods. v^* is the fraction of foreign firms that choose PCP for final goods, among all foreign firms facing home PCP intermediate goods. u^* is the fraction of foreign firms that choose PCP for final goods, among all foreign firms facing home LCP intermediate goods.

2.3.2 Equilibrium Conditions

A systematic equilibrium is a collection of allocations $\{C, C^*, W, W^*, M, M^*, B, B^*\}$, and a price system $\{P, P^*, Q, Q^*, P_h, P_f^*, P_{hf}, P_{fh}, S\}$ such that:

- Given the price system, $\{C, C^*, W, W^*, M, M^*, B, B^*, x, x^*\}$ maximise each consumer's utility, subject to the budget constraint.
- $\{Q, Q^*, P_h, P_f^*, P_{hf}, P_{fh}\}$ maximise each firm's expected profits, and each firm's strategies of invoicing currency for both intermediate and final goods are optimal.
- The goods, labour and money markets are clear.

The equations of the model are shown in Table 2.1. Table 2.1(a) shows the optimal conditions for the consumer and the firm. Each worker (consumer) sets the wage as a markup over the marginal rate of substitution between consumption and leisure. A fraction μ of the total workers set wages ex-post (i.e. flexible wages), after the state of the world is realised, whereas the rest $1 - \mu$ workers set wages ex-ante (i.e. fixed wages). Such setting allows for wage stickiness. The nominal discounted factor is defined here as $\kappa_{t-1} = \beta \left(\frac{C_{t-1}^p P_{t-1}}{C_t^p P_t} \right)$. Table 2.1(b) shows the wage and price indexes. Table 2.1(c) describes the market clearing relationships.

2.3.3 Model Solutions

Here I assume that the exogenous money stock in each country follows a random walk in logs:

$$\ln M_{t+1} = \ln M_t + \epsilon_{t+1}, \quad E_t(\epsilon_{t+1}) = 0.$$

The model is solved by linear approximation around an initial non-stochastic equilibrium. The full derivations of the model solutions are shown in Appendix

Table 2.1: Equations of the Model

(a): Optimal conditions for the consumer and the firm	
First order conditions and wages:	
Euler equation: $\frac{C_t^{-\rho}}{P_t} = \beta (1 + r_{t+1}) E_t \frac{C_{t+1}^{-\rho}}{P_{t+1}}$	Flexible wage: $w_t^{fle} = \frac{\omega\eta}{\omega-1} P_t C_t^\rho L$
Money demand: $\frac{M_t}{P_t} = \chi C_t^{\frac{1+r_{t+1}}{r_{t+1}}}$	Fixed wage: $w_t^{fix} = \frac{\omega\eta}{\omega-1} \frac{E_{t-1}(L_t^f)}{E_{t-1}\left(\frac{L_t^f}{P_t C_t^\rho}\right)}$
Intermediate goods prices:	
Home: $q_{ht} = \frac{\lambda_X}{\lambda_X-1} \frac{E_{t-1}(W_t \cdot \kappa_{t-1} X_{ht})}{E_{t-1}(\kappa_{t-1} X_{ht})}$	Final goods prices:
PCP: $q_{hft} = \frac{\lambda_X}{\lambda_X-1} \frac{E_{t-1}(W_t \cdot S_t^{\lambda_X} \Omega_X)}{E_{t-1}(S_t^{\lambda_X} \Omega_X)}$	Home: $p_{ht} = \frac{\lambda}{\lambda-1} \frac{E_{t-1}(MC_t \kappa_{t-1} C_{ht})}{E_{t-1}(\kappa_{t-1} C_{ht})}$
LCP: $q_{hft}^* = \frac{\lambda_X}{\lambda_X-1} \frac{E_{t-1}(W_t \cdot \Omega_X)}{E_{t-1}(S_t \Omega_X)}$	PCP: $p_{hft} = \frac{\lambda}{\lambda-1} \frac{E_{t-1}(MC_t S_t^\lambda \Omega)}{E_{t-1}(S_t^\lambda \Omega)}$
Definitions: $\Omega_X = \kappa_{t-1} Q_{hft}^{*(\lambda_X-\theta_X)} Q_t^{*\theta_X} X_t^*$, $\Omega = \kappa_{t-1} P_{hft}^{*(\lambda-\theta)} P_t^{*\theta} C_t^*$	LCP: $p_{hft}^* = \frac{\lambda}{\lambda-1} \frac{E_{t-1}(MC_t \Omega)}{E_{t-1}(S_t \Omega)}$
(b) Price and wage indexes	
$Q_t = \left[n Q_{ht}^{1-\theta_X} + (1-n) Q_{hft}^{1-\theta_X} \right]^{\frac{1}{1-\theta_X}}$	
$P_t = \left[n P_{ht}^{1-\theta} + (1-n) P_{hft}^{1-\theta} \right]^{\frac{1}{1-\theta}}$ (CPI)	
$W_t = \left[\mu \left(w_t^{fle} \right)^{1-\omega} + (1-\mu) \left(w_t^{fix} \right)^{1-\omega} \right]^{\frac{1}{1-\omega}}$	
(c) Market equilibrium	
Employment (flexible wage): $L_t^{fle} = \mu \left(\frac{w_t^{fle}}{W_t} \right)^{-\omega} \left(\begin{array}{c} Y_{X,ht} + \bar{z} Y_{X,hft} + (1-\bar{z}) Y_{x,hft}^* \\ + Y_{ht} + \xi Y_{hft} + (1-\xi) Y_{hft}^* \end{array} \right)$	
Employment (fixed wage): $L_t^{fix} = (1-\mu) \left(\frac{w_t^{fix}}{W_t} \right)^{-\omega} \left(\begin{array}{c} Y_{X,ht} + \bar{z} Y_{X,hft} + (1-\bar{z}) Y_{x,hft}^* \\ + Y_{ht} + \xi Y_{hft} + (1-\xi) Y_{hft}^* \end{array} \right)$	
Intermediate goods home sales: $Y_{X,ht} = n \left(\frac{Q_{ht}}{Q_t} \right)^{-\theta_X} X_t$	
Intermediate goods foreign sales (PCP): $Y_{X,hft} = (1-n) \left(\frac{q_{hft}}{S_t Q_{hft}^*} \right)^{-\lambda_X} \left(\frac{Q_{hft}^*}{Q_t^*} \right)^{-\theta_X} X_t^*$	
Intermediate goods foreign sales (LCP): $Y_{X,hft}^* = (1-n) \left(\frac{q_{hft}^*}{Q_{hft}^*} \right)^{-\lambda_X} \left(\frac{Q_{hft}^*}{Q_t^*} \right)^{-\theta_X} X_t^*$	
Final goods home sales: $Y_{ht} = n \left(\frac{p_{ht}}{P_t} \right)^{-\theta} C_t$	
Final goods foreign sales (PCP): $Y_{hft} = (1-n) \left(\frac{p_{hft}}{S_t P_{hft}^*} \right)^{-\lambda} \left(\frac{P_{hft}^*}{P_t^*} \right)^{-\theta} C_t^*$	
Final goods foreign sales (LCP): $Y_{hft}^* = (1-n) \left(\frac{p_{hft}^*}{P_{hft}^*} \right)^{-\lambda} \left(\frac{P_{hft}^*}{P_t^*} \right)^{-\theta} C_t^*$	
Balance of payments: $P_t C_t + B_{t+1} + Q_t X_t = (1+r_t) B_t + Q_{ht} Y_{X,ht} + \bar{z} q_{hft} Y_{X,hft} + (1-\bar{z}) \left(S_t q_{hft}^* \right) Y_{X,hft}^* + P_{ht} Y_{ht} + \xi p_{hft} Y_{hft} + (1-\xi) S_t p_{hft}^* Y_{hft}^*$	
Definitions: $\xi = v \bar{z}^* + u - u \bar{z}^*$, $\xi^* = v^* \bar{z} + u^* - u^* \bar{z}$	

2.B. Here $x_{t+j} = \ln X_{t+j} - E_{t-1}(\ln X_{t+j}) = \hat{x}_{t+j} - E_{t-1}(\hat{x}_{t+j})$ is defined as the log deviation from time $t-1$ expectation for any variable X_{t+j} , $j \geq 0$. First, we can take the money market equilibrium for the home country and the analogous conditions for the foreign country, and then linearise the equations. Taking differences, we get:

$$c_t - c_t^* = \frac{1}{\rho} \{ (m_t - m_t^*) - [n\xi + (1-n)\xi^*] s_t \}, \quad (2.19)$$

where $\xi = v\bar{z}^* + u - u\bar{z}^*$ and $\xi^* = v^*\bar{z} + u^* - u^*\bar{z}$ can be interpreted as weighted degrees of pass-through, taking into account the imported inputs incorporated in total exports and the exported inputs in total imports. When there is full pass-through of exchange rates into prices, i.e. $v = v^* = u = u^* = 1$ and $\xi = \xi^* = 1$, PPP holds at all times and the above equation simply represents a monetary model of the exchange rate. On the other hand, when $v = v^* = u = u^* = 0$ and $\xi = \xi^* = 0$, it represents the case of zero pass-through, where shocks to relative consumption are only dependent on shocks to relative money supplies.

Using the period $t+1$ balance of payment condition, labour market and product market clearing equations, we get:³⁸

$$E_t(c_{t+1} - c_{t+1}^*) + \frac{E_t(X_{t+1} - X_{t+1}^*)}{\sigma} = \frac{r}{\sigma} \left[\frac{dB_{t+1}}{(1-n)\bar{P}\bar{C}} \right], \quad (2.20)$$

where $\sigma = 1 + (\rho\theta - \rho)(1 - \gamma - \gamma^*)$ and r is the steady-state interest rate. Before discussing the relationship between the relative consumption level and the relative demand for imported intermediate goods, here the term $E_t(X_{t+1} - X_{t+1}^*)$ is kept in order to make comparisons with the DES (2004). Their result simply shows that an increase in net foreign assets must be accompanied by an increase in relative consumption levels. In comparison, the effect of an increase in net foreign assets (i.e. capital account deficit) is spread over higher relative consumption and higher relative demand for imported intermediate goods (in order to produce more outputs).

From the home and foreign Euler equations, we can obtain the following condition:

$$E_t(c_{t+1} - c_{t+1}^*) = (c_t - c_t^*) - \frac{(1 - n\xi - (1-n)\xi^*)}{\rho} s_t. \quad (2.21)$$

This equation shows the effect of exchange rate shocks on relative consumption growth. An exchange rate depreciation, for example, reduces the expected consumption growth in the home country relative to the foreign country.

Next, I will show the relationship between the relative consumption level and the relative demand for imported intermediate goods. Using the profit-maximising

³⁸ Also, using the notation $dB_{t+1} = B_{t+1} - B_t$.

conditions with the production function we get:

$$E_t(X_{t+1} - X_{t+1}^*) = \sigma' E_t(c_{t+1} - c_{t+1}^*). \quad (2.22)$$

where $\sigma' = \rho [(1 - \theta)(1 - \gamma - \gamma^*) + 1]$. In this equation, all else being equal, whether an increase in relative consumption level is accompanied by higher or lower relative demand for imported intermediate goods depends on the degrees of dependence both countries have on each other.

We may put (2.19) to (2.22) together and get:

$$s_t = \frac{\left(1 + \frac{1+\rho}{r}\right)(m_t - m_t^*)}{\Delta}, \quad (2.23)$$

where $\Delta = \left(1 + \frac{1+\rho}{r}\right) + (\rho - 1)[1 - n\xi - (1 - n)\xi^*] + \rho\theta_X[(1 - n)\bar{z} + n\bar{z}^*] > 0$. The response of the exchange rate to unanticipated money shocks depends on the elasticity of demand for home goods, the inter-temporal elasticity of substitution and the degrees of exchange rate pass-through. Equation (2.23) shows that the degree of aggregate pass-through affects the distribution of exchange rates. In the previous section, I show that exchange rate volatility enters firms' decision rules for currency choice and thus affects the degree of pass-through. Hence there is a two-way relationship between the movement of exchange rates and the degree of pass-through.

2.4 Equilibrium Currency Choice and Endogenous Pass-through

In this section I combine the analyses in the previous two sections and discuss the determination of equilibrium pass-through. Note that input currency denomination is predetermined and exogenous (fixed \bar{z} and \bar{z}^*).³⁹ To incorporate firms' decision rules I first define a function $\Phi(\bar{z}, \bar{z}^*, v, v^*, u, u^*, \sigma_\epsilon^2, \sigma_{\epsilon^*}^2)$ as the relative benefits of pricing final goods in LCP relative to PCP. These functions for type P and type L firms, respectively, are given by:

$$\begin{aligned} \Phi_P(\bar{z}, \bar{z}^*, v, v^*, u, u^*, \sigma_\epsilon^2, \sigma_{\epsilon^*}^2) &= (1 - \gamma) \text{cov}_{t-1}(s_t, w_t) - \left(\frac{1}{2} - \gamma\right) \text{var}_{t-1}(s_t), \\ \Phi_L(\bar{z}, \bar{z}^*, v, v^*, u, u^*, \sigma_\epsilon^2, \sigma_{\epsilon^*}^2) &= (1 - \gamma) \text{cov}_{t-1}(s_t, w_t^*) - \frac{1}{2} \text{var}_{t-1}(s_t). \end{aligned}$$

Similarly, $\Phi^*(\bar{z}, \bar{z}^*, v, v^*, u, u^*, \sigma_\epsilon^2, \sigma_{\epsilon^*}^2)$ is defined as the benefit function for for-

³⁹In Appendix 2.D I show that the decision rule for intermediate goods is exactly the same as the case with no foreign inputs ($\gamma = 0$): $\Phi_X(\bar{z}, \bar{z}^*, v, v^*, u, u^*, \sigma_\epsilon^2, \sigma_{\epsilon^*}^2) = \text{cov}_{t-1}(s_t, w_t) - \frac{1}{2} \text{var}_{t-1}(s_t)$.

eign firms:

$$\begin{aligned}\Phi_P^*(\bar{z}, \bar{z}^*, v, v^*, u, u^*, \sigma_\epsilon^2, \sigma_{\epsilon^*}^2) &= -(1 - \gamma) \text{cov}_{t-1}(s_t, w_t^*) - \left(\frac{1}{2} - \gamma\right) \text{var}_{t-1}(s_t), \\ \Phi_L^*(\bar{z}, \bar{z}^*, v, v^*, u, u^*, \sigma_\epsilon^2, \sigma_{\epsilon^*}^2) &= -(1 - \gamma) \text{cov}_{t-1}(s_t, w_t^*) - \frac{1}{2} \text{var}_{t-1}(s_t).\end{aligned}$$

Table 2.2 uses the model solutions to define the conditional variances of the exchange rate and the covariances between the exchange rate and marginal costs.

Table 2.2: Conditional Variances and Covariances

$\text{var}_{t-1}(s_t)$	$\frac{(1 + \frac{1+\rho}{r})^2 (\sigma_\epsilon^2 + \sigma_{\epsilon^*}^2 - 2\sigma_{\epsilon\epsilon^*})}{\Delta^2}$
$\text{cov}_{t-1}(s_t, w_t)$	$\mu \text{cov}_{t-1}(s_t, w_t^{fle})$
$\text{cov}_{t-1}(s_t, w_t^{fle})$	$\text{cov}_{t-1}(s_t, \epsilon_t) = \frac{(1 + \frac{1+\rho}{r})(\sigma_\epsilon^2 - 2\sigma_{\epsilon\epsilon^*})}{\Delta}$
$\text{cov}_{t-1}(s_t, w_t^*)$	$\mu \text{cov}_{t-1}(s_t, w_t^{*fle})$
$\text{cov}_{t-1}(s_t, w_t^{*fle})$	$\text{cov}_{t-1}(s_t, \epsilon_t^*) = \frac{(1 + \frac{1+\rho}{r})(\sigma_{\epsilon^*}^2 - 2\sigma_{\epsilon\epsilon^*})}{\Delta}$
$\Delta = \left\{ \begin{aligned} &\left(1 + \frac{1+\rho}{r}\right) + (\rho - 1)[1 - n\xi - (1 - n)\xi^*] \\ &+ \rho\theta_X[(1 - n)\bar{z} + n\bar{z}^*] \end{aligned} \right\}$	

2.4.1 The Equilibrium: A Symmetric Case

In the following analysis I focus on a symmetric case where countries are identical in all aspects with identical monetary policy, and same types of firms in both countries follow the same pricing strategies.⁴⁰ In the symmetric case, each type of firms either chooses PCP, LCP or indifferent between pricing in the home or foreign currencies. Therefore we have nine candidates for a symmetric equilibrium:

(A) PCP for type P ($\Phi_P < 0$) and PCP for type L ($\Phi_L < 0$).

(B) PCP for type P ($\Phi_P < 0$) and LCP for type L ($\Phi_L > 0$).

(C) PCP for type P ($\Phi_P < 0$) and mixed for type L ($\Phi_L = 0$).

⁴⁰In the symmetric case $\text{cov}_{t-1}(s_t, w_t^*) = -\text{cov}_{t-1}(s_t, w_t)$ and $\Phi = \Phi^*$.

- (D) LCP for type P ($\Phi_P > 0$) and PCP for type L ($\Phi_L < 0$).
- (E) LCP for type P ($\Phi_P > 0$) and LCP for type L ($\Phi_L > 0$).
- (F) LCP for type P ($\Phi_P > 0$) and mixed for type L ($\Phi_L = 0$).
- (G) Mixed for type P ($\Phi_P = 0$) and PCP for type L ($\Phi_L < 0$).
- (H) Mixed for type P ($\Phi_P = 0$) and LCP for type L ($\Phi_L > 0$).
- (I) Mixed for type P ($\Phi_P = 0$) and mixed for type L ($\Phi_L = 0$).

To establish the existence of a unique equilibrium, I evaluate the Φ functions at each value of v and u , using Table 2.2. In the symmetric case:

$$\Phi_P(z, v, u, \sigma_\epsilon^2) \propto \left[-\left(\frac{1-\mu}{\mu} \right) + \frac{\gamma}{1-\gamma} \right] \tilde{\rho} + [(\rho-1)(1-\xi) + \rho\theta_X \bar{z}], \quad (2.24)$$

$$\Phi_L(z, v, u, \sigma_\epsilon^2) \propto \left[-\left(\frac{1-\mu}{\mu} \right) - \frac{\gamma}{1-\gamma} \right] \tilde{\rho} + [(\rho-1)(1-\xi) + \rho\theta_X \bar{z}], \quad (2.25)$$

where \propto denotes "proportional to" and $\tilde{\rho} \equiv 1 + \frac{1+\rho}{r}$. Firms' decision rules depend on the weighted pass-through ξ , the measure of PCP inputs \bar{z} , the consumption elasticity ρ , the elasticity of substitution between home and foreign inputs θ_X and the share of ex-post wage setters μ . When there is no use of foreign inputs ($\gamma = 0$), firms' decision rules are identical.

By evaluating their benefit functions Φ , each firm has to choose a currency for their final goods. In any unique equilibrium, the strategy taken by each type of firm has to be the best response to the other's, such that no firm has an incentive to deviate.

Using (2.24) and (2.25) I establish the following proposition.

Proposition 2 *In the symmetric case, the only unique equilibrium is:*

(a) *Full exchange rate pass-through if*

$$\begin{aligned} \theta_X &< \frac{\tilde{\rho}}{\rho \bar{z}} \left(\frac{1-\mu}{\mu} - \frac{\gamma}{1-\gamma} \right) - \frac{\rho-1}{\rho}, \text{ when } \rho \geq 1 \\ \theta_X &< \frac{\tilde{\rho}}{\rho \bar{z}} \left(\frac{1-\mu}{\mu} - \frac{\gamma}{1-\gamma} \right), \text{ when } \rho < 1. \end{aligned}$$

This is case (A) with symmetric PCP ($u = v = \xi = 1$).⁴¹

⁴¹Note also $\frac{1-\mu}{\mu} > \frac{\gamma}{1-\gamma}$.

(b) *Zero exchange rate pass-through if*

$$\begin{aligned}\theta_X &> \frac{\tilde{\rho}}{\rho\bar{z}} \left(\frac{1-\mu}{\mu} + \frac{\gamma}{1-\gamma} \right) - \frac{\rho-1}{\rho}, \text{ when } \rho \geq 1, \\ \theta_X &> \frac{\tilde{\rho}}{\rho\bar{z}} \left(\frac{1-\mu}{\mu} + \frac{\gamma}{1-\gamma} \right) + \frac{1-\rho}{\rho\bar{z}}, \text{ when } \rho < 1.\end{aligned}$$

This is case (E) with symmetric LCP ($u = v = \xi = 0$).

(c) *Incomplete exchange rate pass-through otherwise. The equilibrium degree of pass-through is:*

(c-i) $\bar{\xi} = 1 - \bar{z}$ if

$$\begin{aligned}\frac{\tilde{\rho}}{\rho\bar{z}} \left(\frac{1-\mu}{\mu} - \frac{\gamma}{1-\gamma} \right) &< \theta_X < \frac{\tilde{\rho}}{\rho\bar{z}} \left(\frac{1-\mu}{\mu} + \frac{\gamma}{1-\gamma} \right) - \frac{\rho-1}{\rho\bar{z}}, \\ &\text{when } \rho \geq 1, \\ \frac{\tilde{\rho}}{\rho\bar{z}} \left(\frac{1-\mu}{\mu} - \frac{\gamma}{1-\gamma} \right) + \frac{1-\rho}{\rho} &< \theta_X < \frac{\tilde{\rho}}{\rho\bar{z}} \left(\frac{1-\mu}{\mu} + \frac{\gamma}{1-\gamma} \right) + \frac{1-\rho}{\rho}, \\ &\text{when } \rho < 1.\end{aligned}$$

This is case (D) where all type P firms use LCP ($v = 0$) and all type L firms use PCP ($u = 1$) and $\bar{\xi} = v\bar{z} + u - u\bar{z} = 1 - \bar{z}$.

(c-ii) $\bar{\xi} = 1 - \frac{\rho\theta_X\bar{z}}{1-\rho} + \frac{\tilde{\rho}}{1-\rho} \left(\frac{1-\mu}{\mu} + \frac{\gamma}{1-\gamma} \right)$ if

$$\begin{aligned}\rho &< 1 \text{ and} \\ \frac{\tilde{\rho}}{\rho\bar{z}} \left(\frac{1-\mu}{\mu} + \frac{\gamma}{1-\gamma} \right) + \frac{1-\rho}{\rho} &< \theta_X < \frac{\tilde{\rho}}{\rho\bar{z}} \left(\frac{1-\mu}{\mu} + \frac{\gamma}{1-\gamma} \right) + \frac{1-\rho}{\rho\bar{z}},\end{aligned}$$

This is case (F) where all type P firms use LCP ($v = 0$) and all type L firms are indifferent. There is a $\bar{u} \in (0, 1)$ such that $\Phi_L = 0$:

$$\bar{u} = \frac{1}{1-\bar{z}} \left[1 - \frac{\rho\theta_X\bar{z}}{1-\rho} + \frac{\tilde{\rho}}{1-\rho} \left(\frac{1-\mu}{\mu} + \frac{\gamma}{1-\gamma} \right) \right].$$

(c-iii) $\bar{\xi} = 1 - \frac{\rho\theta_X\bar{z}}{1-\rho} + \frac{\tilde{\rho}}{1-\rho} \left(\frac{1-\mu}{\mu} - \frac{\gamma}{1-\gamma} \right)$ if

$$\begin{aligned}\rho &< 1 \text{ and} \\ \frac{\tilde{\rho}}{\rho\bar{z}} \left(\frac{1-\mu}{\mu} - \frac{\gamma}{1-\gamma} \right) &< \theta_X < \frac{\tilde{\rho}}{\rho\bar{z}} \left(\frac{1-\mu}{\mu} - \frac{\gamma}{1-\gamma} \right) + \frac{1-\rho}{\rho},\end{aligned}$$

This is case (G) where all type P firms are indifferent and all type L firms use PCP ($u = 1$). There is a $\bar{v} \in (0, 1)$ such that $\Phi_P = 0$:

$$\bar{v} = 1 - \frac{\rho\theta_X}{1-\rho} + \frac{\tilde{\rho}}{(1-\rho)\bar{z}} \left(\frac{1-\mu}{\mu} - \frac{\gamma}{1-\gamma} \right).$$

Proof. See Appendix 2.C. ■

In equilibrium (a), both types of firms have an incentive to set prices in their own currencies (PCP), whatever others do. For symmetric PCP to be the unique equilibrium, both the consumption elasticity ρ and the elasticity of substitution between home and foreign inputs θ_X have to be small enough (both positive). The equilibrium conditions show that if ρ is greater than 1, there is a stricter condition for θ_X (to be even smaller). This is because lower ρ and θ_X lead to a higher exchange rate volatility.⁴² As a result, firms have more incentive to choose PCP and symmetric PCP is more likely to be the unique equilibrium. In the equilibrium, both countries have full exchange rate pass-through.

In equilibrium (b), both types of firms have an incentive to set prices in the foreign currencies (LCP), whatever others do. For symmetric LCP to be the unique equilibrium, θ_X has to be high enough.

In equilibrium (c), we have incomplete exchange rate pass-through with three possible outcomes. In (c-i) all firms use the same currency of their foreign inputs for exports, i.e. type P firms use LCP and type L firms use PCP. Therefore the degree of pass-through is exactly the share of type L firms ($1 - \bar{z}$). In (c-ii) and (c-iii) the degree of pass-through depends on the elasticities ρ and θ_X , the (exogenous) measure of PCP inputs \bar{z} , the degree of wage stickiness μ and the expenditure share of imported inputs γ .

These results show how input currency denomination affects firms' currency choice and accordingly the equilibrium degree of pass-through (the relationship between \bar{z} and $\bar{\xi}$). Also, we can examine the relationship between the elasticity of substitution and pass-through systematically. I discuss these results in the next subsections.

Note that in (c-ii) and (c-iii) there is a positive relationship between the degree of wage stickiness and the degree of pass-through: the stickier the wages (smaller μ), the higher the pass-through (higher $\bar{\xi}$).⁴³ Recall the analysis in Section 2.2 (see

⁴²See $\text{var}(s_t)$ in 2.2 as a function of ρ and θ_X . It can be shown that $\partial \text{var}(s_t)/\partial \rho < 0$ and $\partial \text{var}(s_t)/\partial \theta_X < 0$. This result is consistent with the results of DES (2004).

⁴³Compared to DES (2004), the use of intermediate goods brings about an extra result: when all wages are adjusted ex-post ($\mu = 1$), the symmetric PCP equilibrium does not hold because θ_X cannot be negative.

Figure 2.2) which shows that an increase in γ makes type P firms more likely to use LCP (which leads to lower pass-through) and type L firms more likely to use PCP (which leads to higher pass-through). Therefore, the overall effect of γ on pass-through is ambiguous depending on which effect dominates.

The reason why the other candidates cannot hold as the unique equilibrium is shown technically in Appendix D. Intuitively, this is because in any state of the world type L firms are less likely to use LCP ($\Phi_L < \Phi_P$ for given levels $\bar{z}, v, u, \sigma_\epsilon^2$) than type P firms. When all type P firms use PCP, it is impossible for type L firms to use LCP or stay indifferent. Hence case (B) and (C) are ruled out. Similarly, if type P firms are indifferent, it is impossible for type L firms to use LCP only. Hence case (H) is ruled out. For case (I) to hold as a unique equilibrium it requires that both types of firms are indifferent between the two currencies. This is only possible when $\gamma = 0$.

2.4.2 Input Currency Denomination and Equilibrium Pass-through

From the equilibrium results in Proposition 2 we can examine how input currency denomination affects firms' currency choice and accordingly the equilibrium degree of pass-through. In the following analysis I focus on the cases with incomplete pass-through (equilibrium (c)).

The results show that a change in the measure of PCP inputs \bar{z} directly alters the degree of pass-through through firms' currency choice for final goods. To see this, consider an example with an increase in \bar{z} for the home country. In (c-i) this directly translates into lower pass-through since more (type P) firms now use LCP. This is the direct channel through which input currency denomination affects pass-through.

There is a second indirect channel through the two-way relationship between exchange rates and pass-through shown in (2.23). In (c-ii) when all type L firms are indifferent between the two currencies, an increase in \bar{z} leads to a decrease in the equilibrium share of PCP choice \bar{u} . Similarly, in (c-iii) when all type P firms are indifferent between the two currencies, an increase in \bar{z} leads to a decrease in the equilibrium share of PCP choice \bar{v} . Any change of \bar{z} first affects the degree of pass-through (through the change of firm composition), which alters the distribution of exchange rate. Exchange rate changes, in turn, affects firms' decision rules and hence determines a new level of equilibrium pass-through.

Overall the degree of pass-through is decreasing in the measure of PCP inputs for all three equilibrium cases with incomplete pass-through.⁴⁴ This result suggests that input currency denomination has strong implications for the degree of pass-

⁴⁴Note that $\partial \bar{\xi} / \partial \bar{z} < 0$ in all three cases.

through. The more an industry or a country is dependent on imported inputs priced in the foreign currency, the lower the degree of pass-through.

2.4.3 Elasticity of Substitution and Equilibrium Pass-through

The equilibrium conditions also provide some insight on the link between the elasticity of substitution and pass-through. Graphing all the equilibrium conditions together I get a negative relationship between the elasticity of substitution between home and foreign intermediate goods θ_X and the equilibrium pass-through.⁴⁵ This result comes from comparing the conditions for θ_X and the equilibrium pass-through $\bar{\xi}$ in the 5 equilibrium cases.

2.5 Concluding Remarks

This paper extends the general equilibrium framework of Devereux, Engel and Storgaard (2004) by allowing for trade in intermediate goods in a two-country model with endogenous exchange rate pass-through. The main contribution of the paper is to identify the link between input currency denomination and endogenous exchange rate pass-through through firms' currency choice for final goods.

The equilibrium results show a negative relationship between the share of inputs denominated in the foreign currency and the degree of exchange rate pass-through. This happens through 2 channels: (i) A direct channel through the change of firm composition. When more firms face PCP inputs (type P), for example, pass-through is lower because type P firms are more likely to use LCP compared to type L firms; (ii) an indirect channel through exchange rate changes which alter firms' decision rules for final goods and in turn the degree of pass-through. Another key result of the paper is that a higher elasticity of substitution between home and foreign intermediate goods is associated with lower equilibrium pass-through.

Empirical evidence has shown that in the UK pass-through to domestic prices exhibits significant heterogeneity across UK industries. The manufacturing and raw materials sectors, for example, have much higher pass-through than the energy sector. (Mumtaz, Oomen and Wang, 2006) One possible direction for future empirical work is to examine whether this can be attributed to different uses of imported inputs and accordingly different currency behaviours across industries.

⁴⁵The graph is not reported but available upon request.

2.A Proof of Proposition 1

In this appendix I provide a proof of firms' decision rules developed in Proposition 1. Following the solution technique of Devereux et al. (2004), I drop the subscript i for simplicity. From (2.7) and (2.9), the expected discounted profits under PCP are given as:

$$\begin{aligned} E\Pi^{PCP} &= \left(\frac{\lambda}{\lambda-1} \frac{E(MC \cdot S^\lambda \Omega)}{E(S^\lambda \Omega)} \right)^{1-\lambda} E[S^\lambda \Omega] \\ &\quad - \left(\frac{\lambda}{\lambda-1} \frac{E(MC \cdot S^\lambda \Omega)}{E(S^\lambda \Omega)} \right)^{-\lambda} E[MC \cdot S^\lambda \Omega] \\ &= \tilde{\lambda} E[S^\lambda \Omega]^\lambda E[MC \cdot S^\lambda \Omega]^{1-\lambda}, \end{aligned} \quad (\text{A-1})$$

where $\tilde{\lambda} = \frac{1}{\lambda-1} \left(\frac{\lambda}{\lambda-1} \right)^{-\lambda}$, $\Omega = \kappa P_{hf}^{*(\lambda-\theta)} P^{*\theta} C^*$. Note that (A-1) suffices because prices are preset one period in advance, i.e. $E_{t-1}(P_t) = P_t$. This expression may also be rewritten as:

$$\tilde{\lambda} [E \exp(\lambda \ln S) \exp(\ln \Omega)]^\lambda [E \exp(\ln MC) \exp(\lambda \ln S) \exp(\ln \Omega)]^{1-\lambda}. \quad (\text{A-2})$$

In the next step, I take a second order approximation for the first term:

$$\begin{aligned} E \exp(\lambda \ln S) \exp(\ln \Omega) &\approx \exp(\lambda E \ln S) \exp(E \ln \Omega) \\ &\quad \times \left[1 + \frac{\lambda^2}{2} \text{var}(\ln S) + \frac{1}{2} \text{var}(\ln \Omega) + \lambda \text{cov}(\ln \Omega, \ln S) \right]. \end{aligned} \quad (\text{A-3})$$

Using the same approximation for $E \exp(\ln MC) \exp(\lambda \ln S) \exp(\ln \Omega)$, we get an approximation for $E\Pi^{PCP}$:

$$\begin{aligned} &\Sigma \left[1 + \frac{\lambda^2}{2} \text{var}(\ln S) + \frac{1}{2} \text{var}(\ln \Omega) + \lambda \text{cov}(\ln \Omega, \ln S) \right]^\lambda \\ &\times \left[1 + \frac{1}{2} \text{var}(\ln MC) + \frac{\lambda^2}{2} \text{var}(\ln S) + \frac{1}{2} \text{var}(\ln \Omega) + \lambda \text{cov}(\ln MC, \ln S) + \text{cov}(\ln MC, \ln \Omega) + \lambda \text{cov}(\ln S, \ln \Omega) \right]^{1-\lambda}. \end{aligned} \quad (\text{A-4})$$

where $\Sigma = \tilde{\lambda} \exp(\lambda E \ln S) \exp(E \ln \Omega) \exp[(1-\lambda)E \ln MC]$. Taking logs and using the approximation $\ln(1+x) \approx x$, the expected discounted profits thus become:

$$\begin{aligned} \ln E\Pi^{PCP} &\approx \ln \Sigma + \frac{\lambda^2}{2} \text{var}(\ln S) + \frac{1}{2} \text{var}(\ln \Omega) + \frac{1-\lambda}{2} \text{var}(\ln MC) \\ &\quad + \left[\lambda \text{cov}(\ln S, \ln \Omega) + \lambda(1-\lambda) \text{cov}(\ln MC, \ln S) + (1-\lambda) \text{cov}(\ln MC, \ln \Omega) \right]. \end{aligned} \quad (\text{A-5})$$

Now, from (2.8) and (2.10), the expected discounted profits under LCP are given as:

$$E\Pi^{LCP} = \tilde{\lambda} E[S\Omega]^\lambda E[MC \cdot \Omega]^{1-\lambda}. \quad (\text{A-6})$$

Using the same approximation, they may be written as:

$$\begin{aligned} \ln E\Pi^{LCP} &\approx \ln \Sigma + \frac{\lambda}{2} \text{var}(\ln S) + \frac{1}{2} \text{var}(\ln \Omega) + \frac{1-\lambda}{2} \text{var}(\ln MC) \\ &\quad + [\lambda \text{cov}(\ln S, \ln \Omega) + (1-\lambda) \text{cov}(\ln MC, \ln \Omega)]. \end{aligned} \quad (\text{A-7})$$

Now, we can compare (A-5) and (A-7) and get the following condition for $E\Pi^{PCP} > E\Pi^{LCP}$ to hold:

$$\frac{1}{2} \text{var}(s) - \text{cov}(s, mc) > 0, \quad (\text{A-8})$$

where $s = \ln(S)$, and $mc = \ln(MC)$. Substituting in the equations of marginal costs, (2.5) and (2.6), proposition 1 follows. Note that prices of foreign inputs do not appear in the decision rules because they are preset at time $t-1$

2.B Solution Technique

The technique used to solve the system is a linear approximation around an initial symmetric steady state where next foreign assets are zero, all prices are equal and the exchange rate is unity. Define $\hat{x}_t = \ln X_t - \ln \bar{X}$ as a log deviation from the initial steady state. Also, define $x_{t+j} = \hat{x}_{t+j} - E_{t-1}\hat{x}_{t+j}$ as the unexpected component of the deviation from the initial steady state. The linearised versions of the pricing equations are:

$$\begin{aligned} \hat{q}_{hft} &= E_{t-1}\hat{w}_t, \quad \hat{q}_{hft}^* = E_{t-1}(\hat{w}_t - \hat{s}_t), \\ \hat{q}_{fht} &= E_{t-1}(\hat{w}_t^* + \hat{s}_t), \quad \hat{q}_{fht}^* = E_{t-1}\hat{w}_t^*, \end{aligned}$$

$$\begin{aligned} \hat{p}_{ht}(q) &= \hat{p}_{ht}(q^*) = (1-\gamma) E_{t-1}\hat{w}_t + \gamma E_{t-1}\hat{w}_t^* + \gamma E_{t-1}\hat{s}_t, \\ \hat{p}_{hft}(q) &= \hat{p}_{hft}(q^*) = (1-\gamma) E_{t-1}\hat{w}_t + \gamma E_{t-1}\hat{w}_t^* + \gamma E_{t-1}\hat{s}_t, \\ \hat{p}_{hft}^*(q) &= \hat{p}_{hft}^*(q^*) = (1-\gamma) E_{t-1}\hat{w}_t + \gamma E_{t-1}\hat{w}_t^* - (1-\gamma) E_{t-1}\hat{s}_t, \end{aligned}$$

$$\begin{aligned} \hat{p}_{ft}^*(q) &= \hat{p}_{ft}^*(q^*) = (1-\gamma^*) E_{t-1}\hat{w}_t^* + \gamma^* E_{t-1}\hat{w}_t - \gamma^* E_{t-1}\hat{s}_t, \\ \hat{p}_{fht}^*(q) &= \hat{p}_{fht}^*(q^*) = (1-\gamma^*) E_{t-1}\hat{w}_t^* + \gamma^* E_{t-1}\hat{w}_t - \gamma^* E_{t-1}\hat{s}_t, \\ \hat{p}_{fht}(q) &= \hat{p}_{fht}(q^*) = \left[\begin{aligned} &(1-\gamma^*) E_{t-1}\hat{w}_t^* + \gamma^* E_{t-1}\hat{w}_t \\ &+ (1-\gamma^*) E_{t-1}\hat{s}_t \end{aligned} \right]. \end{aligned}$$

Also, we can calculate the price indexes:

$$\begin{aligned}
\widehat{Q}_t &= n\widehat{Q}_{ht} + (1-n)\widehat{Q}_{fht} \\
&= \begin{bmatrix} nE_{t-1}\widehat{w}_t + (1-n)E_{t-1}\widehat{w}_t^* \\ +(1-n)(1-z)E_{t-1}\widehat{s}_t + (1-n)z^*\widehat{s}_t \end{bmatrix}, \\
\widehat{Q}_t^* &= n\widehat{Q}_{hft}^* + (1-n)\widehat{Q}_{ft}^* \\
&= \begin{bmatrix} nE_{t-1}\widehat{w}_t + (1-n)E_{t-1}\widehat{w}_t^* \\ -n(1-z)E_{t-1}\widehat{s}_t - nz\widehat{s}_t \end{bmatrix}, \\
\widehat{p}_t &= n\widehat{p}_{ht} + (1-n)\widehat{p}_{fht} \\
&= n((1-\gamma)E_{t-1}\widehat{w}_t + \gamma E_{t-1}\widehat{w}_t^* + \gamma E_{t-1}\widehat{s}_t) \\
&\quad + (1-n) \begin{bmatrix} (1-\gamma^*)E_{t-1}\widehat{w}_t^* + \gamma^*E_{t-1}\widehat{w}_t \\ +(1-\xi^*-\gamma^*)E_{t-1}\widehat{s}_t + \xi^*\widehat{s}_t \end{bmatrix}, \tag{B-1}
\end{aligned}$$

$$\begin{aligned}
\widehat{p}_t^* &= n\widehat{p}_{hft}^* + (1-n)\widehat{p}_{ft}^* \\
&= n \begin{bmatrix} (1-\gamma)E_{t-1}\widehat{w}_t + \gamma E_{t-1}\widehat{w}_t^* \\ -(1-\xi-\gamma)E_{t-1}\widehat{s}_t - \xi(\widehat{s}_t) \end{bmatrix} \\
&\quad + (1-n)((1-\gamma^*)E_{t-1}\widehat{w}_t^* + \gamma^*E_{t-1}\widehat{w}_t - \gamma^*E_{t-1}\widehat{s}_t). \tag{B-2}
\end{aligned}$$

Linearising the Euler equations and the money market clearing conditions gives:

$$\widehat{p}_t + \rho\widehat{c}_t = E_t(\widehat{p}_{t+1} + \rho\widehat{c}_{t+1}), \tag{B-3}$$

$$\widehat{p}_t^* + \rho\widehat{c}_t^* = E_t(\widehat{p}_{t+1}^* + \rho\widehat{c}_{t+1}^*), \tag{B-4}$$

$$\widehat{m}_t - \widehat{p}_t = \rho\widehat{c}_t, \tag{B-5}$$

$$\widehat{m}_t^* - \widehat{p}_t^* = \rho\widehat{c}_t^*. \tag{B-6}$$

Linearising the balance of payment condition gives:

$$\begin{aligned}
& \hat{c}_t + \frac{d\hat{B}_{t+1}}{\bar{P} \bar{C}} + (\hat{Q}_t + \hat{X}_t - \hat{p}_t) = (1+r) \frac{d\hat{B}_t}{\bar{P} \bar{C}} + n (\hat{Y}_{X,ht} + \hat{Q}_{ht}) \\
& + (1-n) \left[\begin{aligned} & (\hat{Q}_t^* + \hat{X}_t^* + \hat{s}_t - \hat{p}_t) + (1-\theta_X) (\hat{Q}_{hft}^* - \hat{Q}_t^*) \\ & + z(1-\lambda_X)(\hat{q}_{hft} - \hat{Q}_{hft}^* - \hat{s}_t) \\ & + (1-z)(1-\lambda_X)(\hat{q}_{hft}^* - \hat{Q}_{hft}^*) \end{aligned} \right] \\
& + n [\hat{c}_t + (1-\theta) (\hat{p}_{ht} - \hat{p}_t)] \\
& + (1-n) \left\{ \begin{aligned} & \xi \left[\begin{aligned} & (1-\lambda) (\hat{p}_{hft} - \hat{s}_t - \hat{p}_{hft}^*) \\ & + (1-\theta) (\hat{p}_{hft}^* - \hat{p}_t^*) \\ & + (\hat{s}_t + \hat{p}_t^* - \hat{p}_t) + \hat{c}_t^* \end{aligned} \right] \\ & + (1-\xi) \left[\begin{aligned} & (1-\lambda) (\hat{p}_{hft}^* - \hat{p}_{hft}) \\ & + (1-\theta) (\hat{p}_{hft}^* - \hat{p}_t^*) \\ & + (\hat{s}_t + \hat{p}_t^* - \hat{p}_t) + \hat{c}_t^* \end{aligned} \right] \end{aligned} \right\}. \tag{B-7}
\end{aligned}$$

Finally, linearising the labour supply schedules for both flexible and fixed wage sectors gives:

$$\hat{w}_t^{fle} = \hat{p}_t + \rho \hat{c}_t + \varphi \hat{l}_t^{fle}, \tag{B-8}$$

$$\hat{w}_t^{fix} = E_{t-1} \left(\hat{p}_t + \rho \hat{c}_t + \varphi \hat{l}_t^{fix} \right), \tag{B-9}$$

$$\hat{w}_t^{*fle} = \hat{p}_t^* + \rho \hat{c}_t^* + \varphi \hat{l}_t^{*fle}, \tag{B-10}$$

$$\hat{w}_t^{*fix} = E_{t-1} \left(\hat{p}_t^* + \rho \hat{c}_t^* + \varphi \hat{l}_t^{*fix} \right). \tag{B-11}$$

To get (2.19) of the text, use (B-5) and (B-6), together with (B-1) and (B-2), and the definition $x_t = \hat{x}_t - E_{t-1} \hat{x}_t$.

To get (2.20) of the text, firstly use the balance of payment condition (B-7), substituting in the pricing equations, and taking expectations dated $t-1$, gives:

$$E_{t-1}(\hat{c}_t - \hat{c}_t^*) + E_{t-1}(\hat{X}_t - \hat{X}_t^*) = \left[\begin{aligned} & \frac{rd\hat{B}_t}{(1-n)\bar{P}\bar{C}} + [(1-\theta)(1-\gamma-\gamma^*)] \\ & \times E_{t-1}(\hat{w}_t - \hat{w}_t^* - \hat{s}_t) \end{aligned} \right]. \tag{B-12}$$

Doing the same for the employment equations of both home and foreign, gives:

$$E_{t-1}(\hat{l}_t - \hat{l}_t^*) = -[\theta_X + \theta(1-\gamma-\gamma^*)] E_{t-1}(\hat{w}_t - \hat{w}_t^* - \hat{s}_t). \tag{B-13}$$

Noting that in expected terms of the linear approximation, employment and wages of both types of workers are the same. Finally, doing the same for the labour supply

equations gives:

$$E_{t-1}(\hat{w}_t - \hat{w}_t^* - \hat{s}_t) = \rho E_{t-1}(\hat{c}_t - \hat{c}_t^*) + \varphi E_{t-1}(\hat{l}_t - \hat{l}_t^*). \quad (\text{B-14})$$

From (B-13) and (B-14), we get:

$$E_{t-1}(\hat{w}_t - \hat{w}_t^* - \hat{s}_t) = \frac{\rho}{1 + \varphi [\theta_X + \theta(1 - \gamma - \gamma^*)]} E_{t-1}(\hat{c}_t - \hat{c}_t^*). \quad (\text{B-15})$$

Combining (B-12) and (B-15) and updating to period t (also using the fact that $E_{t-1}d\hat{B}_{t+1} = d\hat{B}_t$) we get (2.20) of the text.

To get (2.22) of the text, take the profit-maximising conditions for both domestic and foreign firms:

$$\begin{aligned} X_{fh} &= \frac{rPY}{Q_{fh}}, \\ X_{hf}^* &= \frac{rP^*Y^*}{Q_{hf}^*}, \end{aligned}$$

where PY (P^*Y^*) represents total sales of home (foreign) final goods. Linearising these equations and taking differences gives:

$$E_{t-1}(\hat{X}_t - \hat{X}_t^*) = [1 + (1 - \theta)(1 - \gamma - \gamma^*)] E_{t-1}(\hat{w}_t - \hat{w}_t^* - \hat{s}_t). \quad (\text{B-16})$$

Combining (B-15) and (B-16), we get (2.22) of the text.

2.C Proof of Proposition 2

In order to examine the 9 candidates for a unique equilibrium, we need the equilibrium conditions for different types of firms. Given what others do, if $\Phi > 0$ (< 0), firms choose LCP(PCP). If $\Phi = 0$, firms are indifferent between the two options. Below I discuss the conditions for each case.

Case (A)

For type P firms:

(P.1) When others PCP ($v = 1$; $u = 1$ and $\xi = 1$), $\Phi_P < 0$:

$$\left(\frac{\gamma}{1 - \gamma} - \frac{1 - \mu}{\mu} \right) \tilde{\rho} + \rho \theta_X \bar{z} < 0.$$

(P.2) When others LCP ($v = 0$; $u = 1$ and $\xi = 1 - \bar{z}$), $\Phi_P < 0$:

$$\left(\frac{\gamma}{1 - \gamma} - \frac{1 - \mu}{\mu} \right) \tilde{\rho} + [(\rho - 1)\bar{z} + \rho \theta_X \bar{z}] < 0.$$

For type L firms:

(L.1) When others PCP ($u = 1$; $v = 1$ and $\xi = 1$), $\Phi_L < 0$:

$$\left(\frac{-\gamma}{1-\gamma} - \frac{1-\mu}{\mu} \right) \tilde{\rho} + \rho \theta_X \bar{z} < 0.$$

(L.2) When others LCP ($u = 0$; $v = 1$ and $\xi = \bar{z}$), $\Phi_L < 0$:

$$\left(\frac{-\gamma}{1-\gamma} - \frac{1-\mu}{\mu} \right) \tilde{\rho} + [(\rho - 1)(1 - \bar{z}) + \rho \theta_X \bar{z}] < 0.$$

The optimal strategies described above are taken regardless of what other firms do. In (P.1), for example, the condition says that when all others choose PCP, PCP is the optimal choice. (P.2) says that when all others choose LCP, PCP is still the optimal choice. This guarantees that no firm has an incentive to deviate. Solving the equilibrium yields the conditions in Proposition 2 (a).

Case (B)

For type P firms:

(P.1) When others PCP ($v = 1$; $u = 0$ and $\xi = \bar{z}$), $\Phi_P < 0$.

(P.2) When others LCP ($v = 0$; $u = 0$ and $\xi = 0$), $\Phi_P < 0$.

For type L firms:

(L.1) When others PCP ($u = 0$; $v = 1$ and $\xi = \bar{z}$), $\Phi_L > 0$.

(L.2) When others LCP ($u = 1$; $v = 1$ and $\xi = 1$), $\Phi_L > 0$.

There is contradiction in the conditions.

Case (C)

For type P firms:

(P.1) When others PCP ($v = 1$; $u = \bar{u}$ and $\xi = \bar{z} + \bar{u}(1 - \bar{z})$), $\Phi_P < 0$.

(P.2) When others LCP ($v = 0$; $u = \bar{u}$ and $\xi = \bar{u}(1 - \bar{z})$), $\Phi_P < 0$.

For type L firms:

(L.1) When others PCP ($u = 1$; $v = 1$ and $\xi = 1$), $\Phi_L > 0$.

(L.2) When others LCP ($u = 0$; $v = 1$ and $\xi = \bar{z}$), $\Phi_L < 0$.

There is a contradiction in the conditions.

Case (D)

For type P firms:

(P.1) When others LCP ($v = 0$; $u = 1$ and $\xi = 1 - \bar{z}$), $\Phi_P > 0$:

$$\left(\frac{\gamma}{1-\gamma} - \frac{1-\mu}{\mu} \right) \tilde{\rho} + [(\rho-1)\bar{z} + \rho\theta_X\bar{z}] > 0$$

(P.2) When others LCP ($v = 1$; $u = 1$ and $\xi = 1$), $\Phi_P > 0$:

$$\left(\frac{\gamma}{1-\gamma} - \frac{1-\mu}{\mu} \right) \tilde{\rho} + \rho\theta_X\bar{z} > 0$$

For type L firms:

(L.1) When others PCP ($u = 1$; $v = 0$ and $\xi = 1 - \bar{z}$), $\Phi_L < 0$:

$$\left(\frac{-\gamma}{1-\gamma} - \frac{1-\mu}{\mu} \right) \tilde{\rho} + [(\rho-1)\bar{z} + \rho\theta_X\bar{z}] < 0$$

(L.2) When others LCP ($u = 0$; $v = 0$ and $\xi = 0$), $\Phi_L < 0$:

$$\left(\frac{-\gamma}{1-\gamma} - \frac{1-\mu}{\mu} \right) \tilde{\rho} + [(\rho-1) + \rho\theta_X\bar{z}] < 0$$

Solving the equilibrium yields the conditions in Proposition 2 (c-i). In equilibrium $v = 0$ and $u = 1$. Using the definition of pass-through $\xi = \bar{v}\bar{z} + \bar{u}(1 - \bar{z})$ we can derive the equilibrium pass-through as $\bar{\xi} = 1 - \bar{z}$.

Case (E)

For type P firms:

(P.1) When others LCP ($v = 0$; $u = 0$ and $\xi = 0$), $\Phi_P > 0$:

$$\left(\frac{\gamma}{1-\gamma} - \frac{1-\mu}{\mu} \right) \tilde{\rho} + [(\rho-1) + \rho\theta_X\bar{z}] > 0.$$

(P.2) When others PCP ($v = 1$; $u = 0$ and $\xi = \bar{z}$), $\Phi_P > 0$:

$$\left(\frac{\gamma}{1-\gamma} - \frac{1-\mu}{\mu} \right) \tilde{\rho} + [(\rho-1)(1 - \bar{z}) + \rho\theta_X\bar{z}] > 0.$$

For type L firms:

(L.1) When others LCP ($u = 0$; $v = 0$ and $\xi = 0$), $\Phi_L > 0$:

$$\left(\frac{-\gamma}{1-\gamma} - \frac{1-\mu}{\mu} \right) \tilde{\rho} + [(\rho-1) + \rho\theta_X \bar{z}] > 0.$$

(L.2) When others LCP ($u = 1$; $v = 0$ and $\xi = 1 - \bar{z}$), $\Phi_L > 0$:

$$\left(\frac{-\gamma}{1-\gamma} - \frac{1-\mu}{\mu} \right) \tilde{\rho} + [(\rho-1)\bar{z} + \rho\theta_X \bar{z}] > 0.$$

Solving the equilibrium yields the conditions in Proposition 2 (b).

Case (F)

For type P firms:

(P.1) When others LCP ($v = 0$; $u = \bar{u}$ and $\xi = \bar{u}(1 - \bar{z})$), $\Phi_P > 0$:

$$\left(\frac{\gamma}{1-\gamma} - \frac{1-\mu}{\mu} \right) \tilde{\rho} + [(\rho-1)(1 - \bar{u}(1 - \bar{z})) + \rho\theta_X \bar{z}] > 0.$$

(P.2) When others PCP ($v = 1$; $u = \bar{u}$ and $\xi = \bar{z} + \bar{u}(1 - \bar{z})$), $\Phi_P > 0$:

$$\left(\frac{\gamma}{1-\gamma} - \frac{1-\mu}{\mu} \right) \tilde{\rho} + [(\rho-1)(1 - \bar{z})(1 - \bar{u}) + \rho\theta_X \bar{z}] > 0.$$

For type L firms:

(L.1) When others LCP ($u = 0$; $v = 0$ and $\xi = 0$), $\Phi_L < 0$:

$$\left(\frac{-\gamma}{1-\gamma} - \frac{1-\mu}{\mu} \right) \tilde{\rho} + [(\rho-1) + \rho\theta_X \bar{z}] < 0.$$

(L.2) When others LCP ($u = 1$; $v = 0$ and $\xi = 1 - \bar{z}$), $\Phi_L > 0$:

$$\left(\frac{-\gamma}{1-\gamma} - \frac{1-\mu}{\mu} \right) \tilde{\rho} + [(\rho-1)\bar{z} + \rho\theta_X \bar{z}] > 0.$$

Solving the equilibrium yields the conditions in Proposition 2 (c-ii). Also there exists a \bar{u} such that $\Phi_L(v = 0; \xi = \bar{u}(1 - \bar{z})) = 0$:

$$\bar{u} = \frac{1}{(1 - \bar{z})} \left\{ 1 - \frac{1}{(\rho-1)} \left(\frac{\gamma}{1-\gamma} + \frac{1-\mu}{\mu} \right) \tilde{\rho} + \frac{\rho\theta_X \bar{z}}{(\rho-1)} \right\}.$$

Using this equation and $\xi = \bar{v}\bar{z} + \bar{u}(1 - \bar{z})$ we can derive the equilibrium pass-through:

$$\bar{\xi} = 1 - \frac{\rho\theta_X \bar{z}}{1-\rho} + \frac{1}{1-\rho} \left(\frac{\gamma}{1-\gamma} + \frac{1-\mu}{\mu} \right) \tilde{\rho}.$$

Case (G)

For type P firms:

(P.1) When others LCP ($v = 0$; $u = 1$ and $\xi = 1 - \bar{z}$), $\Phi_P < 0$:

$$\left(\frac{\gamma}{1-\gamma} - \frac{1-\mu}{\mu} \right) \tilde{\rho} + [(\rho-1)\bar{z} + \rho\theta_X\bar{z}] < 0.$$

(P.2) When others PCP ($v = 1$; $u = 1$ and $\xi = 1$), $\Phi_P > 0$:

$$\left(\frac{\gamma}{1-\gamma} - \frac{1-\mu}{\mu} \right) \tilde{\rho} + \rho\theta_X\bar{z} > 0.$$

For type L firms:

(L.1) When others LCP ($u = 0$; $v = \bar{v}$ and $\xi = \bar{v}\bar{z}$), $\Phi_L < 0$:

$$\left(\frac{-\gamma}{1-\gamma} - \frac{1-\mu}{\mu} \right) \tilde{\rho} + [(\rho-1)(1-\bar{v}\bar{z}) + \rho\theta_X\bar{z}] < 0.$$

(L.2) When others LCP ($u = 1$; $v = \bar{v}$ and $\xi = \bar{v}\bar{z} + 1 - \bar{z}$), $\Phi_L < 0$:

$$\left(\frac{-\gamma}{1-\gamma} - \frac{1-\mu}{\mu} \right) \tilde{\rho} + [(\rho-1)\bar{z}(1-\bar{v}) + \rho\theta_X\bar{z}] < 0.$$

Solving the equilibrium yields the conditions in Proposition 2 (c-iii). Also there exists a \bar{v} such that $\Phi_P(u = 1; \xi = \bar{v}\bar{z} + 1 - \bar{z}) = 0$:

$$\bar{v} = 1 + \frac{\rho\theta_X}{(\rho-1)} + \frac{1}{(\rho-1)\bar{z}} \left(\frac{\gamma}{1-\gamma} - \frac{1-\mu}{\mu} \right) \tilde{\rho}.$$

Case (H)

For type P firms:

(P.1) When others LCP ($v = 0$; $u = 0$ and $\xi = 0$), $\Phi_P < 0$.

(P.2) When others PCP ($v = 1$; $u = 0$ and $\xi = \bar{z}$), $\Phi_P > 0$.

For type L firms:

(L.1) When others LCP ($u = 0$; $v = \bar{v}$ and $\xi = \bar{v}\bar{z}$), $\Phi_L > 0$.

(L.2) When others LCP ($u = 1$; $v = \bar{v}$ and $\xi = \bar{v}\bar{z} + 1 - \bar{z}$), $\Phi_L > 0$.

There is a contradiction in the conditions.

Case (I)

For type P firms:

(P.1) When others LCP ($v = 0$; $u = \bar{u}$ and $\xi = \bar{u}(1 - \bar{z})$), $\Phi_P < 0$.

(P.2) When others PCP ($v = 1$; $u = \bar{u}$ and $\xi = \bar{z} + \bar{u}(1 - \bar{z})$), $\Phi_P > 0$.

For type L firms:

(L.1) When others LCP ($u = 0$; $v = \bar{v}$ and $\xi = \bar{v}\bar{z}$), $\Phi_L < 0$.

(L.2) When others LCP ($u = 1$; $v = \bar{v}$ and $\xi = \bar{v}\bar{z} + 1 - \bar{z}$), $\Phi_L > 0$.

This equilibrium only exists if $\gamma = 0$. The equilibrium pass-through can be shown as:

$$\xi = \left(1 + \frac{1}{\rho - 1}\right) - \left(\frac{1 - \mu}{\mu}\right) \tilde{\rho} + \frac{\rho \theta_X \bar{z}}{\rho - 1}.$$

Q.E.D.

2.D Extension: Currency Choice for Intermediate Goods

If we allow for firms to also preset a currency for their intermediate goods, the decision rule would be:

$$\begin{aligned} \Phi_X(\bar{z}, \bar{z}^*, v, v^*, u, u^*, \sigma_\epsilon^2, \sigma_{\epsilon^*}^2) &= cov_{t-1}(s_t, w_t) - \frac{1}{2} var_{t-1}(s_t). \\ \Phi_X^*(\bar{z}, \bar{z}^*, v, v^*, u, u^*, \sigma_\epsilon^2, \sigma_{\epsilon^*}^2) &= -cov_{t-1}(s_t, w_t^*) - \frac{1}{2} var_{t-1}(s_t). \end{aligned}$$

In an symmetric case the benefits function (of LCP relative to PCP) can be shown as:

$$\Phi_X(\bar{z}, v, u, \sigma_\epsilon^2) \propto (-\tilde{\rho}) \left(\frac{1 - \mu}{\mu}\right) + (\rho - 1)(1 - \xi) + \rho \theta_X \bar{z}.$$

In this case all firms have to be indifferent between the two options. This is because I focus on a symmetric case. If all firms PCP we have a model of DES (2004) and if all firms LCP it is as if we have a model with no imported inputs ($\gamma = 0$). There is a $\bar{z} \in (0, 1)$ such that $\Phi_X = 0$. Adding these conditions to the 5 unique equilibrium cases yields the equilibrium \bar{z} :

(a) Full exchange rate pass-through ($\xi = 1$): $\bar{z} = \frac{\tilde{\rho}}{\rho \theta_X} \frac{1 - \mu}{\mu}$.

- (b) Zero exchange rate pass-through ($\xi = 0$): $\bar{z} = \frac{1}{\rho\theta_X} \left[\tilde{\rho} \left(\frac{1-\mu}{\mu} \right) - (\rho - 1) \right]$.
- (c-i) Incomplete exchange rate pass-through ($\bar{\xi} = 1 - \bar{z}$): $\bar{z} = \tilde{\rho} \left(\frac{1-\mu}{\mu} \right) [(\rho - 1) + \rho\theta_X]^{-1}$.

Case (c-ii) and (c-iii) are ruled out because they can only be an equilibrium when $\gamma = 0$.

Chapter 3

Imported Inputs and Invoicing Currency Choice: Theory and Evidence from UK Transaction Data

3.1 Introduction

When selling to a foreign market, an exporter can invoice the transaction in its own currency (producer currency pricing or PCP), in the currency of the destination country (local currency pricing or LCP) or in the currency of a third country (vehicle currency pricing or VCP). The choice of invoicing currency directly affects how domestic prices respond to changes in exchange rates. Hence, from a policy perspective, it has far-ranging implications for the international transmission of macroeconomic shocks, the effectiveness of monetary policy, and the choice of exchange rate regimes. While most studies treat the choice of invoicing currency as exogenous when examining its macroeconomic implications, the current paper focuses instead on the determinants of invoicing currency choice.⁴⁶

More precisely, this paper examines how exporting firms' dependence on imported inputs affects their invoicing currency choice. Are there marked differences in invoicing currency choice between exporters that use imported inputs and exporters that do not? When choosing an invoicing currency, do exporting firms take into account the currency used for their imported inputs? These questions are of particular interest as trade in intermediate inputs is an important empirical regularity. For example, trade in intermediate goods constitutes about 60 percent of

⁴⁶See, among others, Corsetti and Pesenti (2005) and Devereux and Engel (2002) for the implications for monetary and exchange rate policies.

total UK trade.⁴⁷

Despite the relevance of trade in intermediate goods, theoretical work on its implications for invoicing currency and macroeconomic aggregates remains sparse.⁴⁸ From an empirical point of view, the limitation of the existing literature is due to the lack of disaggregated data on invoicing currency. For a long time little was known beyond a number of broad stylised facts, based mainly on aggregated data. For instance, trade in primary products is mostly denominated in US dollars, while trade between developing and industrialized countries is predominantly invoiced in the industrialized country's currency. It is also acknowledged that inflationary currencies are less likely to be used in foreign trade.⁴⁹ This paper aims at filling both theoretical and empirical gaps in the literature.

I derive a theoretical framework in which the exporter is assumed to pre-set prices and its invoicing currency to maximise expected profits under exchange rate uncertainty. An important feature of the model is that the exporter chooses its invoicing currency endogenously. The model predicts that the exporting firms that are more dependent on imported inputs are less likely to use their own currency, all else being equal. The intuition behind this result is that pricing in the foreign currency provides a natural hedge for firms that use foreign currency-denominated inputs. The model also predicts that a volatile currency is less likely to be used for invoicing (consistent with the finding of Devereux, Engel and Storgaard, 2004).

In order to test the theoretical predictions, I use a unique and highly disaggregated dataset on UK import and export transactions with non-EU countries in 2011, recorded by Her Majesty's Revenue and Customs (HMRC). For each transaction, I observe the trader ID, country of dispatch or destination, product and industry codes, value of transaction and invoicing currency. The econometric analysis consists of two parts. The main part focuses on the choice of invoicing currency for UK exports (2.54 million transactions). The second part examines the currency denomination for UK imports (7.31 million transactions).

In the main analysis, I first identify exporters' use of imported inputs together with the currencies used for these inputs.⁵⁰ To the best of my knowledge, this is the

⁴⁷Source: HMRC trade statistics. Trade in intermediate goods is also related to the following terms: vertical specialization, outsourcing and fragmentation. See Hummels, Ishii and Yi (2001) for definitions.

⁴⁸Ghosh (2009) shows in a model that trade in intermediate goods may be the underlying factor of the empirical decline of exchange rate pass-through. However, he focuses on firms' pricing to market behaviour and does not consider currency choice.

⁴⁹See, for example, Grassman (1973), McKinnon (1979) and Tavlas (1991). Also, see Kamps (2006) for a discussion.

⁵⁰I define imported inputs as goods for industrial use, and the categorization of goods is based on the Broad Economic Categories (BEC). The BEC classification decomposes goods into three end-use categories: consumption (final), intermediate and capital goods. Capital goods are divided into BEC 41 (capital goods except transport equipment) and BEC 521 (transport equipment for industrial use). I treat both intermediate and capital goods as industrial inputs.

first paper matching trader IDs from both import and export data for a firm-level analysis of currency of invoicing. I then attempt to explain whether the currency used for imported inputs affects exporters' choice of invoicing currency. Overall, the results strongly support the theoretical predictions. First, I find that exporters using imported inputs are less likely to use sterling compared to exporters that do not rely on foreign inputs. Second, among the exporters that use imported inputs, the more the exporter is dependent on imported inputs priced in the foreign currency, the more likely the same currency is used for exports. Another key result is that high exchange rate volatility significantly shifts UK exporters' invoicing choice away from the volatile currency.

Other findings shed some light on relating currency choice to firm characteristics. For instance, larger UK exporters are less inclined to use their domestic currency. This supports the argument that larger firms are more likely to hedge using financial instruments because hedging incurs a fixed cost that large firms are more likely to afford.⁵¹ In contrast, all else being equal experienced firms (trading for more than five years in exporting markets) are more inclined to use PCP relative to VCP. This might suggest higher bargaining power for more experienced firms.⁵²

To complement my main analysis, I also look into the currency denomination for UK imports. Since I do not observe the use of imported inputs for the exporters from different exporting countries, I use a systematic measure of value added to gross exports (VAX ratios) computed by Johnson and Noguera (2012) to proxy for the dependence on imported inputs at the country level. If a country heavily relies on imported inputs, the value added relative to gross exports should be lower. Hence VAX ratios are inversely related to the dependence on imported inputs. This is the first paper to use VAX ratios in examining invoicing currency choice. I find that countries more dependent on foreign inputs systematically use less of their own currency for exports (PCP is less likely).⁵³

In both analyses, I also control for a number of different factors. These include: (i) macroeconomic considerations, such as exchange rate volatility (Devereux et al., 2004) and transaction costs of exchange (Devereux and Shi, 2013); (ii) industry characteristics, such as market competition (Bacchetta and van Wincoop, 2003) and price-sensitivity of demand (Bacchetta and van Wincoop, 2005); (iii) strategic characteristics, such as bargaining between exporters and importers (Goldberg and Tille, 2008) and (iv) destination characteristics.

⁵¹See, for instance, Martin and Méjean (2012) for survey results of 3,013 exporting firms located in five EMU countries.

⁵²Goldberg and Tille (2008) consider a bargaining between importers and exporters when deciding on the invoicing currency. They argue that larger firms have a stronger bargaining power.

⁵³I also use a further disaggregated VAX ratios at the country-industry level, and the results still hold. These ratios are computed by Johnson and Noguera based on GTAP database, and are not published in their paper.

This paper is related to several strands of literature. There is an extensive theoretical literature on the determinants of invoicing currency.⁵⁴ My main contribution is to add an alternative but complementary determinant of invoicing currency, namely firms' use of imported inputs.

Empirical evidence on currency choice in international trade is scarce. Most existing studies document country- or industry-specific determinants of invoicing currency choice, rather than firm-level characteristics.⁵⁵ One exception is Friberg and Wilander (2008) with a survey study on the currency considerations of Swedish exporting firms. They find that smaller Swedish firms and firms selling differentiated products are more likely to use Swedish kronor (PCP), a finding that is consistent with my results. The paper that is the closest to mine is by Goldberg and Tille (2011) who document the importance of strategic interaction and bargaining power in determining currency choice using a disaggregated dataset of Canadian import transactions.⁵⁶ My paper focuses instead on linking firm-level characteristics such as firm size, firm experience, and the dependence on imported inputs to the choice of invoicing currency and offering evidence from UK transaction data.

This paper also relates to the growing literature that examines how invoicing currency affects firms' price adjustments and accordingly endogenous exchange rate pass-through. This literature documents differences in price adjustments for goods invoiced in different currencies (see Floden and Wilander, 2006, and Gopinath, Itskhoki and Rigobon, 2010). Furthermore, some recent studies have looked into the direct relationship between the use of imported inputs and the degree of pass-through (see Amiti, Itskhoki and Konings, 2014). Understanding the factors that drive the choice of invoicing currency sheds some light on the heterogeneity of pass-through into prices and inflation across industries.

Finally, there is an active literature on measuring the domestic content of exports.⁵⁷ This paper is an example of the application of the VAX ratios of Johnson and Noguera (2012). I use the ratios to capture the degree of dependence on imported inputs at the country and country-industry levels.

The paper is structured as follows. The next section sets out a simple model to show how firms' choice of invoicing currency is affected by the presence of imported inputs. Section 3.3 presents the dataset and offers descriptive statistics. Section

⁵⁴See, among others, Baron (1976), Giovannini (1988), Donnenfeld and Zilcha (1991) and Friberg (1998) for early literature that takes a micro perspective.

⁵⁵One example is Donnenfeld and Haug (2003) who consider country size and exchange rate uncertainty as key determinants for invoicing in Canadian imports. Also, Wilander (2005) analyses currency use for Swedish exports, using country aggregates such as GDP, distance and inflation rates as explanatory variables.

⁵⁶They use industry-level variables such as market shares of exporters and transaction sizes to proxy for the bargaining power of exporters and importers.

⁵⁷See, among others, Hummels et al. (2001).

3.4 presents the main analysis of invoicing currency choice for UK exporters and provides robustness checks. The analysis of currency denomination in imports is undertaken in section 3.5. Section 3.6 concludes.

3.2 A Model of Imported Inputs and Currency Choice

In this section I develop a framework that relates the choice of invoicing currency to the dependence on imported inputs. The cost structure of the firm follows Halpern, Koren and Szeidl (2011) to allow for imported inputs.⁵⁸ I then build on Devereux et al. (2004) to derive the firm's decision rule for choosing an invoicing currency.⁵⁹

3.2.1 Demand

Consider a risk-neutral firm i that sells a differentiated good to a foreign country and faces a CES demand function:

$$D(p_i) = \left(\frac{p_i}{P_{hf}^*} \right)^{-\lambda} \left(\frac{P_{hf}^*}{P^*} \right)^{-\theta} C^*, \quad (3.1)$$

where D is the quantity demanded, p_i is the firm's price, P_{hf}^* is the price index for all home goods sold in the foreign country and P^* is the foreign consumer price index (all denominated in foreign currency). C^* is the foreign demand shifter that is independent of prices. The parameter λ is the elasticity of substitution across varieties with $\lambda > 1$. The parameter θ is the foreign elasticity of demand for domestic goods.

3.2.2 Production and Import Intensity

A risk-neutral firm i uses labour L_i and intermediate goods X_i in order to produce following a Cobb-Douglas production function with constant returns to scale:

$$Y_i = A_i X_i^\gamma L_i^{1-\gamma}, \quad (3.2)$$

where A_i is firm i 's productivity and $\gamma \in [0, 1]$ measures the expenditure share on intermediate inputs. The cost of labour is the wage rate W .

Intermediate goods consist of two varieties, domestic and foreign, which are imperfect substitutes:

⁵⁸Halpern, Koren and Szeidl (2011) do not consider the currency of invoicing but focus on the relationship between firms' choice of import varieties and productivity.

⁵⁹Devereux et al. (2004) consider endogenous currency choice without considering imported inputs.

$$X_i = \left[Z_i^{\frac{\delta}{1+\delta}} + (a_i M_i)^{\frac{\delta}{1+\delta}} \right]^{\frac{1+\delta}{\delta}}, \quad (3.3)$$

where Z_i and M_i are the quantities of domestic and imported inputs, respectively. The elasticity of substitution between domestic and foreign varieties is $(1 + \delta) > 1$.⁶⁰ I assume that the price of the domestic input Z_i is Q , denominated in domestic currency. The foreign input M_i is priced in foreign currency with the price SQ^* , S being the exchange rate (defined as the domestic price of foreign currency) and Q^* being the price denominated in foreign currency (hence starred).⁶¹

The parameter a_i captures how productive firm i is in using the foreign inputs, which in this model varies across firms and directly determines the degree of dependence on imported inputs. A high a_i represents high productivity advantage for firm i in using the foreign inputs, and vice versa.⁶²

Firm i needs to pay a sunk cost f_i in terms of labour in order to import foreign inputs.⁶³ Given output, the firm first chooses the amount of inputs to minimize its total costs subject to the production technology. The total cost of the firm is given by $WL_i + QZ_i + SQ^*M_i + Wf_i$, which can be written as the sum of a variable cost plus a fixed cost:

$$TC_i = \mu_i Y + Wf_i.$$

The marginal cost μ_i can be derived as:

$$\mu_i = \frac{C}{A_i b_i^\gamma}, \quad (3.4)$$

where $C = (Q/\gamma)^\gamma [W/(1 - \gamma)]^{1-\gamma}$ is a cost index and $b_i \equiv \left[1 + \left(\frac{a_i}{SQ^*/Q} \right)^\delta \right]^{1/\delta}$ is the productivity-enhancing effect from using imported inputs. The productivity-

⁶⁰Since domestic and foreign inputs are imperfect substitutes, production is possible without the use of imported inputs. Note that the model also accommodates the cases of perfect substitutes (when $\delta \rightarrow \infty$) and perfect complements (when $\delta \rightarrow 0$). In the appendix I discuss firms' use of imported inputs and their decision rules under these cases.

⁶¹The model can be extended to allow a fraction of the imported inputs to be denominated in home currency. This extension reduces the degree of input price uncertainty, but it does not qualitatively change the model's predictions. In the empirical section, I will take into account each firm's fraction of imported inputs denominated in home currency.

⁶²When $a_i > 1$, using foreign inputs brings productivity advantage. In contrast, $a_i < 1$ implies productivity disadvantage. The price-adjusted productivity, $a_i/(SQ^*/Q)$, captures the advantage of a unit of home currency spent on the foreign variety relative to the home variety. This term also relates to Grossman and Helpman (1993)'s definition of 'quality' as the advantage in services provided by a good relative to its cost.

⁶³Fixed costs can explain the fact that some firms use zero foreign inputs. The model can be extended to incorporate a set of differentiated intermediate goods, so that fixed costs play a role in determining the optimal choice of the cut-off set. This extension, however, does not change the model's predictions on currency choice.

enhancing effect is increasing in the productivity parameter a_i .

With this cost structure, I define ψ_i as the share of costs spent on imported inputs in total costs of intermediate goods:

$$\psi_i \equiv \frac{SQ^* M_i}{SQ^* M_i + QZ_i}.$$

The parameter ψ_i directly captures the dependence of the firm on foreign inputs. Home share of inputs ($1 - \psi_i$) can be shown as:

$$1 - \psi_i = \left[1 + \left(\frac{a_i}{SQ^*/Q} \right)^\delta \right]^{-1}. \quad (3.5)$$

Home share of inputs depends on the productivity parameter a_i . A firm with higher productivity gain from using imported inputs (higher a_i) has higher dependence on imported inputs (lower $1 - \psi_i$). The detailed model derivation is shown in Appendix 3.A.

3.2.3 PCP versus LCP

After deciding on the amount of inputs, the firm is then assumed to pre-set optimal prices and invoicing currency one period ahead by maximising its profits using a discount factor κ .⁶⁴ If the firm sets its price in its own currency (PCP), then the expected discounted profits are:

$$E\Pi_i^{PCP}(p_i) = E \left[\kappa (p_i - \mu_i) \left(\frac{p_i}{SP_{hf}^*} \right)^{-\lambda} \left(\frac{P_{hf}^*}{P^*} \right)^{-\theta} C^* \right]. \quad (3.6)$$

If the firm sets its price in the foreign currency (LCP), then the expected discounted profit is:

$$E\Pi_i^{LCP}(p_i^*) = E \left[\kappa (Sp_i^* - \mu_i) \left(\frac{p_i^*}{P_{hf}^*} \right)^{-\lambda} \left(\frac{P_{hf}^*}{P^*} \right)^{-\theta} C^* \right]. \quad (3.7)$$

The profit-maximising prices under PCP and LCP, respectively, are:

$$p_i = \frac{\lambda}{\lambda - 1} \cdot \frac{E(\mu_i \cdot S^\lambda \Omega)}{E(S^\lambda \Omega)}, \quad (3.8)$$

$$p_i^* = \frac{\lambda}{\lambda - 1} \cdot \frac{E(\mu_i \cdot \Omega)}{E(S\Omega)}, \quad (3.9)$$

⁶⁴Note that the expectation takes place in period $t - 1$ when the firms sets its price for period t . The time subscripts are omitted here for simplicity.

where $\Omega = \kappa P_{hf}^{*(\lambda-\theta)} P^{*\theta} C^*$.

Following Devereux et al. (2004), I take a second order approximation of the two expected profit functions and establish the firm's decision rule.

Proposition 3 *A domestic firm using foreign inputs sets its price for the foreign market in PCP if:*

$$\frac{1}{2} \text{var}(\ln S) > \frac{\gamma}{\delta} \text{cov}[\ln(1 - \psi_i), \ln S]. \quad (3.10)$$

The firm chooses LCP vice versa.

Proof. See Appendix 3.B. ■

Proposition 3 says that all else being equal exchange rate volatility, captured by high $\text{var}(\ln S)$ in (3.10), makes the firm prefer PCP. In contrast, the covariance between exchange rates and the home share of inputs $(1 - \psi_i)$ makes the firm prefer LCP. The former effect captures the firm's consideration of expected revenues whereas the latter captures the consideration of expected costs. Note that in the model setting, the exchange rates only affect the firm's total costs through the use of imported inputs denominated in the foreign currency. Therefore the right hand side in (3.10) is shut down for firms that do not use imported inputs. Given any exchange rate volatility ($\text{var}(\ln S) > 0$), they use only the home currency.⁶⁵ Below I discuss the two effects in turn.

The effect of exchange rate volatility enters the decision rule through the firm's consideration of expected revenues, as in Devereux et al. (2004). When the firm chooses PCP, the price is stable whereas the quantity (foreign demand) is subject to exchange rate uncertainty. On the other hand, when the firm chooses LCP, the quantity is stable whereas the price is subject to exchange rate uncertainty. The firm therefore faces a trade-off between stabilising price and stabilising quantity. The curvature of revenue functions matters for the optimal currency choice. Technically, the expected revenue function under PCP is convex in the exchange rate and linear under LCP. Holding all other variables constant, an increase in the exchange rate variance increases expected revenues under PCP relative to LCP.⁶⁶

⁶⁵This model result is supported by empirical evidence from UK data. The majority of UK exporters that do not use imported inputs price their exports in sterling only. See Section 3.3 for details.

⁶⁶The expected revenue functions are $E \left[p_i \left(\frac{p_i}{SP_{hf}^*} \right)^{-\lambda} \left(\frac{P_{hf}^*}{P^*} \right)^{-\theta} C^* \right]$ under PCP and $E \left[SP_i^* \left(\frac{p_i}{P_{hf}^*} \right)^{-\lambda} \left(\frac{P_{hf}^*}{P^*} \right)^{-\theta} C^* \right]$ under LCP.

The right hand side in (3.10) enters the decision rule through the firm's consideration of expected costs. For example, if there is a depreciation in the home currency (higher S), then foreign inputs become more expensive which leads to a higher marginal cost. In this case, there will be an expenditure switching of the firm from using imported inputs to domestic inputs (higher $1 - \psi_i$). The covariance term is positive and captures how responsive the firm is to input price uncertainty. A more responsive firm has more incentive to choose LCP for its exports. Intuitively, choosing LCP provides a natural hedge for the firm. Also, this effect is stronger if the domestic and foreign inputs are less substitutable (with low elasticity of substitution δ).

To see how the degree of dependence on imported inputs affects the decision rule, I rewrite the right hand side in (3.10) in terms of the productivity-enhancing effect b_i :

$$\begin{aligned} R.H.S &= \frac{\gamma}{\delta} cov [\ln (1 - \psi_i), \ln S] \\ &= -\gamma cov (\ln b_i, \ln S), \end{aligned}$$

where the absolute value of $cov (\ln b_i, \ln S)$ is increasing in the degree of dependence on imported inputs ψ_i .⁶⁷ This implies that the right hand side is higher if the firm is more dependent on imported inputs, all else being equal. Put differently, a firm more dependent on imported inputs is more likely to use LCP. Based on the above discussion, the following testable hypotheses follow.

Testable hypothesis 1 *When exporting to a country with a more volatile exchange rate, exporters are more likely to use PCP relative to LCP, all else being equal.*

Testable hypothesis 2 *The more exporters are dependent on imported inputs priced in the foreign currency, the more likely they are in using the same currency for their exports.*

In this section I show in a two-country framework that the use of imported inputs denominated in the foreign currency alters a domestic firm's choice of invoicing currency. The model yields two testable hypotheses relating to exchange rate volatility and the dependence on imported inputs. The model can also be extended to allow for the case of vehicle currency pricing (VCP). In this case, a domestic firm's decision rule also depends on the covariance between the two exchange rates vis-à-vis the vehicle currency. This extension is shown in Appendix 3.C.

⁶⁷Note that $\partial \ln b_i / \partial \ln S = (-1/\gamma) \psi_i < 0$. See Appendix 3.A for proof.

3.3 The UK Trade Dataset and Descriptive Statistics

3.3.1 The Dataset

I use a highly disaggregated dataset for UK non-EU trade transactions in 2011 recorded by HMRC. The dataset is confidential and not publicly available.⁶⁸ For each trade transaction, I observe the trader ID, the country of dispatch (for imports) or the destination country (for exports), product and industry codes, the value of transaction and the currency of settlement. After dropping observations with no information on the invoicing currency, I am left with a sample that accounts for 95.1% of total imports (7.31 million observations) and 86.3% of total exports (2.54 million observations).

Arguably, one advantage of UK trade data is the diversity in trading partners. In 2011, the total number of trading partners is around 190 for both imports and exports. The main partners are the US, which represents 16% of imports and 29% of exports, and China which accounts for 15% of imports and 6% of exports.⁶⁹

3.3.2 A Broad Assessment of Invoicing Currency for UK Trade

I first report a broad assessment of invoicing currency choice for UK trade. In 2011, 76 currencies were used for UK exports and 103 for imports. Table 3.1 presents the shares of currency choice, the shares of pricing strategies in PCP/LCP/VCP and Table 3.2 shows the breakdowns of the shares of pricing strategies by industry, destination and category of goods.

The first observation is that there is an asymmetry in the currency use for exports relative to imports—the dominant currency for imports is the US dollar (64.7%), whereas UK exports are mainly priced in sterling (57.4%). This pattern is at odds with Swedish evidence reported in Friberg and Wilander (2008) that Swedish exporters mainly use their customers' currencies for exports. The Euro accounts for a small share mainly because the data do not include trade with EU countries. Given that the US only represents 16% of total imports and 29% of exports, it is clear that the US dollar is used extensively as a vehicle currency, particularly for imports. As shown in Table 3.1, VCP is the dominant strategy for imports whereas PCP is the dominant strategy for exports. The sectoral breakdown in Panel A of Table 3.2 also shows that these patterns hold across sectors, except for beverages

⁶⁸The full HMRC dataset covers trade transactions between 1996 and 2011. Declaring currency of invoicing became a requirement in 2010 for non-EU imports and in 2011 for exports (if the transaction value is greater than £100,000). In 2011, non-EU imports accounted for 49.5% of total UK imports and non-EU exports accounted for 46.5% of total UK exports.

⁶⁹These 190 trading partners include countries and some autonomous areas such as Hong Kong. Other main partners are the East and South East Asia (25% of imports and 21% of exports) and Europe excluding EU countries (21% of imports and 26% of exports).

and tobacco (SITC1) in imports.⁷⁰

The breakdown by destination shown in Panel B of Table 3.2 shows that there is a significant variation in pricing strategies across destinations. In particular, almost all imports from the US are priced in dollar (82.6%). Also, imports from East and South East Asia have the highest share of goods priced in sterling (42.3%) compared to other destinations. Turning to exports, half of the exports to the US are priced in dollar (50.2%) whereas exports to other destinations are mainly priced in sterling.

Next, I decompose goods into final, intermediate and capital goods according to the Broad Economic Categories (BEC) classification.⁷¹ To the best of my knowledge, this is the first paper using the BEC classification to examine invoicing currency for different categories of goods. As shown in Panel C of Table 3.2, LCP is used more extensively for final goods relative to intermediate and capital goods (in value), especially for imports. This finding relates to the model assumption in Section 3.2 that imported inputs are priced exogenously in the foreign currency. Panel C shows that imports in intermediate goods, in particular, are mainly priced in currencies other than sterling.

The finding that LCP is used more extensively for final goods is also in line with the theoretical argument in Bacchetta and van Wincoop (2003) that final goods producers are more prone to use LCP due to local competition, compared to intermediate goods exporters.⁷² I will test this theoretical prediction formally in the next section.

Table 3.1: Invoicing Currency Choice for UK non-EU Trade in 2011

	Imports	Exports
<i>Shares of Currency Choice (in Value)</i>		
Sterling (£)	24.5	57.4
US dollar (\$)	64.7	37.1
Euro (€)	5.3	2.8
Others	5.5	2.7
Sum	100.0	100.0
<i>Shares of Pricing Strategy (in Value)</i>		
Producer Currency Pricing (PCP)	18.8	57.4(£)
Local Currency Pricing (LCP)	24.5(£)	14.0
Vehicle Currency Pricing (VCP)	56.7	28.6
Sum	100.0	100.0

⁷⁰VCP includes a wide range of currencies (57 for exports and 75 for imports).

⁷¹The trade shares of final, intermediate and capital goods for UK imports in 2011 are 24.2%, 58.2% and 13.9%, respectively. The figures are 18.4%, 56.8% and 15.7% for exports. Some goods are not classified by the BEC and account for 3.7% of UK imports and 9% of UK exports in 2011.

⁷²In their model, all exports are intermediate goods sold to domestic final goods producers.

Table 3.2: Shares of Pricing Strategy by Industry, Destination and Category

		Imports			Exports		
	1-digit SITC Industry	PCP	LCP(£)	VCP	PCP(£)	LCP	VCP
Panel A	0:Food & live animals	10.5	37.7	51.8	68.0	10.4	21.5
	1:Beverages & tobacco	19.0	68.0	12.9	48.4	33.6	18.1
	2:Crude materials	30.5	30.9	38.5	65.5	2.4	32.0
	3:Mineral fuels	2.7	9.7	87.6	65.0	19.3	15.7
	4:Animal & veg. oils	10.6	3.6	85.8	77.9	6.6	15.5
	5:Chemicals	32.0	33.8	34.2	54.7	28.8	16.5
	6:Manufactured goods	10.2	20.5	69.3	54.8	8.6	36.6
	7:Machinery	24.8	29.6	45.6	58.6	14.1	27.4
	8:Miscellaneous	14.8	36.5	48.7	65.5	15.5	19.0
	9:Not classified	37.3	0.7	62.0	50.7	0.5	48.8
Panel B	Destination Region/Country	PCP	LCP(£)	VCP	PCP(£)	LCP	VCP
	US	82.6	15.6	1.8	50.2	47.2	2.7
	China	0.3	26.0	73.8	62.4	0.1	37.5
	East/SE Asia	6.4	42.3	51.2	57.3	5.9	36.8
	Europe exc. EU	4.6	21.8	73.6	75.5	2.8	21.6
	Other Americas	10.9	24.9	64.2	53.4	7.8	38.8
	All Others	3.7	21.9	74.4	63.5	1.9	34.6
Panel C	The BEC Category	PCP	LCP(£)	VCP	PCP(£)	LCP	VCP
	Final Goods	10.7	41.2	48.1	56.3	27.2	16.5
	Intermediate Goods	18.6	20.1	61.3	56.6	15.8	27.6
	Capital Goods	21.4	25.2	53.4	59.3	13.2	27.5

Notes: classifications used are the Standard International Trade Classification (SITC) and the Broad Economic Categories (BEC).

3.3.3 Importing versus Non-importing Exporters

In the following discussion I turn to descriptive statistics for UK exporters active in 2011. I categorize UK exporters into two groups: *importing exporters* if they use imported inputs and *non-importing exporters* otherwise. The inputs imported by all importing exporters account for 63.4% of all UK imported inputs.⁷³ Table 3.3 presents the differences between the two groups according to their firm facts and pricing strategies. Table 2b presents their export sectors, destinations and categories of goods.

The first fact I document is that importing firms are larger than non-importing exporters in terms of export market share. Among all exporters 32,289 firms (55%) rely on imported inputs and account for 89.5% of total exports. Another characteristic of interest relates to firm experience. Within the group of importing exporters,

⁷³The rest is imported by firms that only sell to domestic markets.

72% (i.e., 23,078 firms) have more than five years of experience in exporting, and they account for about 79.9% of total UK exports; in contrast, within non-importing exporters, only 47% (i.e., 12,520 firms) have more than five years of experience in exporting, with about 7.9% of export share.

Table 3.3 also shows that the difference in pricing strategy between importing and non-importing exporters is significant. I find that a large share of non-importing exporters (75.4%) only use PCP (sterling) for exports, whereas this figure is about 49.9% for importing exporters. Also, a larger share of non-importing exporters (8%) use only VCP, as opposed to 3.5% for importing exporters. More interestingly, only 14% of non-importing firms use a combination of two or three strategies, as opposed to 44% for importing firms.⁷⁴

Do importing exporters use less of PCP because of their importing behaviour and the consideration of the currency used for their imported inputs, or because of other firm characteristics such as firm size (market share) and firm experience? This is the main question that will be explored formally in the next section.

Table 3.4 shows that there is no substantial heterogeneity in export sectors and export destinations between importing and non-importing exporters. Comparing the export shares of different categories of goods, however, we can see that importing exporters have a higher share of exports in intermediate goods compared to non-importing exporters. This finding suggests that firms that use imported inputs also export more intermediate goods, and hence are more engaged in vertical specialization.

Table 3.3: Importing versus Non-importing Exporters: Firm Facts

	Importing	Non-importing
<i>Firm Facts</i>		
Share of Total Export	89.5	10.5
Number of Firms	32,289	26,618
w/ export value in upper 5 th percentile	2,568	377
exporting for more than five years	23,078	12,520
(share of export)	(79.9%)	(7.9%)
<i>Shares of Firms by Pricing Strategy (in Number of Firms)</i>		
All PCP (£)	49.9	75.4
All LCP	2.2	2.5
All VCP	3.5	8.0
Mixed of Two or More Strategies	44.4	14.0
Sum	100.0	100.0

⁷⁴Within the mixed group, the average shares (by value) of PCP, LCP, and VCP are: 60%, 16%, and 24% for importing firms and 59%, 15%, 26% for non-importing firms. It is worth noting that some firms use different currencies for the same good exported to the same country. This may be due to multiple importers.

Table 3.4: Importing versus Non-importing Exporters: Sectors, Destinations and Categories of Goods

	Importing	Non-importing
<i>Shares of exports by 1-digit SITC Industry (in Value)</i>		
0:Food & live animals	1.2	5.7
1:Beverages & tobacco	2.8	1.9
2:Crude materials	2.9	6.2
3:Mineral fuels	7.4	1.8
4:Animal & veg. oils	0.1	0.04
5:Chemicals	17.6	21.5
6:Manufactured goods	12.2	8.6
7:Machinery	41.6	40.4
8:Miscellaneous	12.1	13.1
9:Not classified	2.1	0.8
Sum	100.0	100.0
<i>Shares of Exports by Destination (in Value)</i>		
US	28.6	31.1
China	6.3	7.2
East/SE Asia	22.5	27.8
Europe exc. EU	16.4	14.1
Other Americas	9.0	5.1
All Others	17.2	14.7
Sum	100.0	100.0
<i>Shares of Exports by the BEC Category (in Value)</i>		
Final Goods	17.6	25.0
Intermediate Goods	58.6	41.7
Capital Goods	16.0	13.2
N/A	7.8	20.2
Sum	100.0	100.0

Notes: classifications used are the Standard International Trade Classification (SITC) and the Broad Economic Categories (BEC).

3.4 The Determinants of Invoicing Currency Choice for UK Exporters

I now examine formally how the use of imported inputs affects exporters' choice of invoicing currency for their exports. I use the whole sample of UK exports (2.54 million transactions) and reduce it into the firm-product-destination-currency level (0.65 million observations). The dimension that is eliminated is the frequency of shipping for each exporter (at the product-destination-currency level) within a year.⁷⁵

The dependent variables are dummy variables capturing whether the pricing strategy is PCP, LCP or VCP. The regressions are estimated using a multinomial logit procedure (MNL) which imposes the constraint that the three invoicing al-

⁷⁵ On average UK firms ship four times a year. The reason for collapsing the data is to avoid assigning more weights to firms shipping more regularly.

ternatives are mutually exclusive and exhaustive. Statistical significance in MNL specifications shows the direction in which the explanatory variables shift the likelihood of LCP and VCP away from the PCP (default) option. The estimating equation is:

$$\Pi^{i,c,k}(PCP) = \text{MNL} \left(Firm^i, Macro^c, Industry^k \right), \quad (3.11)$$

where superscripts i , c , and k denote firm, destination (country) and industry, respectively. $Firm^i$ is a set of factors relating to firm characteristics, including the use of imported inputs; $Macro^c$ is a set of macroeconomic factors relating to exchange rates; $Industry^k$ is a set of other measures at the industry level.

I control for within-industry correlation by clustering the standard errors at the HS4 level (1,191 clusters). For the sake of clarity, I only report a subset of results in Table 3.5 together with the associated Akaike Information Criteria (AIC) and Pseudo R-square statistics.⁷⁶ When including only constant terms (not reported), the coefficients are negative and significant for both LCP and VCP options (relative to PCP). This shows an unexplained prominence in PCP use for UK exports.

3.4.1 Imported Inputs Variables

Column (1) only includes variables that are related to imported inputs. To distinguish between importing and non-importing exporters, I use a dummy variable $Import^i$ which takes the value of one if a firm uses imported inputs and zero otherwise. The model in section 3.2 predicts that the use of imported inputs increases the likelihood of firms to shift away from PCP, and this is supported by the data. The coefficients on the variable $Import^i$ are positive and highly significant, which reflects the more prominent use of both LCP and VCP (relative to PCP) for importing exporters.

In order to improve on the use of a dummy variable only, I compute a variable $InputPCP^{i,c}$ which measures the share of inputs that a firm i imports from country c priced in the currency of country c (PCP from the perspective of country c). This can be interpreted as firm i 's "effective" dependence on inputs from country c . The results support Hypothesis 2 that firms highly dependent on imported inputs denominated in the foreign currency are more likely to use LCP relative to PCP.

Given that this variable only captures the bilateral (firm-destination) relationship, I also consider a firm-level ratio $InputLCP^i$ which captures the total share of firm i 's sterling-denominated imported inputs. For example, suppose a UK exporter imports inputs from both the US (denominated in dollars) and China (denominated in sterling), and then produces a final good that sells to the US. The variable

⁷⁶Note that the estimates for MNL regressions are odds ratios, not marginal effects.

Table 3.5: Determinants of Currency Choice for UK Exporters

Dependent Variables	(1)		(2)		(3)		(4)		(5) Binary logistic	(6) Linear prob.	(7) Linear prob.
	LCP	VCP	LCP	VCP	LCP	VCP	LCP	VCP	nPCP=1	nPCP=1	nPCP=1
Firm Characteristics											
<i>Importⁱ</i>	0.78*** (0.04)	0.79*** (0.04)	0.73*** (0.04)	0.80*** (0.04)	0.74*** (0.04)	0.79** (0.04)	0.72*** (0.03)	0.75*** (0.04)	0.08*** (0.11)	0.14*** (0.02)	0.19*** (0.02)
<i>InputPCP^{i,c}</i>	0.25*** (0.03)	-1.64*** (0.08)	0.27*** (0.03)	-1.63*** (0.08)	0.26*** (0.03)	-1.52*** (0.08)	0.24*** (0.03)	-1.56*** (0.08)	0.09*** (0.04)	0.12*** (0.01)	0.02* (0.03)
<i>InputLCPⁱ</i>	-0.40*** (0.04)	-1.11*** (0.05)	-0.42*** (0.04)	-1.12*** (0.04)	-0.39*** (0.05)	-0.11*** (0.04)	-0.40*** (0.04)	-1.11*** (0.04)	-0.18*** (0.10)	-0.17*** (0.02)	-0.20*** (0.00)
<i>ratio^{i,k}</i>			0.99*** (0.14)	0.76*** (0.14)	1.00*** (0.15)	0.73*** (0.14)	1.00*** (0.15)	0.73*** (0.13)	0.16*** (0.14)	0.17*** (0.03)	0.17*** (0.06)
<i>fiveyroidⁱ</i>			0.00 (0.03)	-0.17*** (0.02)	0.12 (0.02)	-0.17*** (0.03)	0.00 (0.02)	-0.18*** (0.03)	-0.01 (0.07)	-0.02 (0.01)	-0.08*** (0.02)
<i>Top10^k</i>			0.34*** (0.03)	0.11*** (0.02)	0.36*** (0.03)	0.11*** (0.02)	0.36*** (0.02)	0.13*** (0.01)	0.02*** (0.02)	0.04*** (0.00)	-0.00 (0.01)
Macroeconomic Factors											
<i>cvGBP^c</i>					6.38*** (0.41)	1.49*** (0.17)	6.41*** (0.49)	1.46*** (0.16)	0.09** (0.23)	0.09** (0.04)	0.39** (0.17)
<i>cvUSD^c</i>					-1.70*** (0.41)	-0.68*** (0.12)	-1.67*** (0.12)	-0.64*** (0.06)	-0.34** (0.17)	-0.32** (0.03)	-0.17** (0.07)
<i>Dpeg^c</i>					-0.65*** (0.06)	-0.14*** (0.02)	-0.64*** (0.06)	-0.12*** (0.02)			-0.01 (0.01)
<i>Epeg^c</i>					-1.98*** (0.34)	0.34*** (0.04)	-1.98*** (0.34)	0.35*** (0.04)			0.02 (0.02)
<i>FX^c</i>					0.04*** (0.00)	-0.04*** (0.00)	0.04*** (0.00)	-0.04*** (0.00)			0.00*** (0.00)
Industry Characteristics											
<i>ClassC^k</i>							0.11** (0.05)	0.01 (0.06)			
vs. Intermediate											
<i>ClassF^k</i>							-0.09 (0.09)	-0.34*** (0.08)			
vs. Intermediate											
<i>RauchR^k</i>							-0.09 (0.08)	-0.17*** (0.08)			
vs. Homogeneous											
<i>RauchN^k</i>							-0.14* (0.08)	-0.27*** (0.08)			
vs. Homogeneous											
Final goods											-0.09** (0.03)
Differentiated goods											-0.04 (0.04)
Constant	-1.60*** (0.17)	-3.75*** (0.24)	-1.74*** (0.18)	-3.61*** (0.23)	-5.57*** (0.21)	-0.73** (0.35)	-5.51*** (0.18)	-0.60*** (0.24)	0.29*** (0.26)	0.14*** (0.05)	0.21*** (0.03)
Industry effects	Yes		Yes		Yes		Yes		Yes	Yes	No
Destination effects	Yes		Yes		Yes		Yes		No	No	No
Obs.	646,441		646,441		646,441		646,441		646,441	646,441	2,540,331
AIC	832,915		831,135		821,296		819,164		-	-	-
Pseudo-R ²	0.155		0.157		0.166		0.170		0.03	Adj. R ² =0.03	Adj. R ² =0.08

Notes: The default option is PCP. Industry effects are dummies for SITC 1-digit sectors. Destination effects are dummies for the US, China, East/SE Asia, Europe excluding EU, other American countries, and all other countries. Clustered standard errors in parentheses (at the HS4 level for column 1-4 and at the firm level for column 5-7). * significant at 10%; ** significant at 5%; *** significant at 1%.

$InputPCP^{i,c}$ only captures the dollar-denominated inputs. Adding the variable $InputLCP^i$ would take the other source of inputs into account. It is therefore a systematic measure of the overall degrees of input price uncertainty facing exporters. Higher $InputLCP^i$ is expected to increase the likelihood of firms to choose PCP. The results are in line with this prediction, particularly at the expense of VCP.

3.4.2 Other Firm Characteristics

In column (2) I add other factors relating to firm characteristics. Firstly, I consider *firm relative size* in terms of market share of exports. I use the variable $ratio^{i,k}$, the share of exports of firm i into an HS4 industry, in order to proxy for firm relative size. I find evidence of currency choice tilted away from PCP for larger firms (with high $ratio^{i,k}$). One possible explanation is that larger firms highly involved in international activities have more incentives and resources to hedge against exchange rate uncertainty using financial instruments. Hence they are more likely to use LCP or VCP.

Secondly, I also consider *firm experience*. The dummy variable $fiveyrol^i$ takes the value one if firm i has more than five years of experience in the exporting market and zero otherwise. The results suggest that more experienced firms are more likely to use PCP relative to VCP. One conjecture is that experienced firms may have more bargaining power since they know the market well and have more information on potential buyers.

Lastly, I consider *transaction size* by adding a dummy variable $Top10^k$ to capture whether a transaction falls in the top 10th percentile of transactions in value within an HS4 industry. Larger transactions are less likely to be priced in PCP in the results. These result support the theoretical prediction of Goldberg and Tille (2008), in which larger transactions capture the bargaining power of importers.⁷⁷ However, it might be the case that larger transactions are done by larger firms, and therefore the variable $Top10^k$ simply captures a similar effect as the firm size variable $ratio^{i,k}$.

3.4.3 Macroeconomic Factors

In column (3) I add a set of macroeconomic factors. Two variables are used to proxy for *exchange rate volatility*: the coefficients of variation of the importer's currency relative to sterling and the US dollar denoted by, respectively, $CVGBP^c$ and $CVUSD^c$. The variables are computed using the IMF's monthly exchange rate data from 2006-2010.⁷⁸ Under exchange rate uncertainty, the theory predicts that the

⁷⁷The results are also consistent with the findings of Friberg and Wilander (2008) and Goldberg and Tille (2011).

⁷⁸I use the period-average nominal exchange rate, IMF's International Financial Statistics series *rf*.

currency of a country with more volatile macroeconomic conditions is unappealing for exporters (Devereux et al., 2004). Hypothesis 1 also says that exchange rate volatility makes PCP more appealing as opposed to LCP. When exporters sell to a country with a more volatile currency against the US dollar (high $CVUSD^c$), they are more likely to use PCP. Exchange rate volatility against sterling, however, gives the opposite result. This may be because sterling experienced an unusually high volatility during the 2006-2009 period.⁷⁹

I also consider *exchange rate pegs*. I use two dummy variables to capture exchange rate pegs with respect to the dollar and the Euro denoted by $Dpeg^c$ and $Epeg^c$, respectively. The peg definition follows the IMF's classification in 2007.⁸⁰ Exchange rate pegs might have mixed effects on exporters' currency choice. On the one hand, an exchange rate peg limits exchange rate volatility and so LCP should be more appealing (Goldberg and Tille, 2011). On the other hand, since the euro zone is excluded, an exchange rate peg might capture a low or unstable macroeconomic performance in emerging markets. Hence LCP should be less appealing. The results are consistent with the second argument. I find that exporters are less likely to use LCP relative to PCP when exporting to countries with exchange rate pegs. Surprisingly, dollar pegs ($Dpeg^c = 1$) do not increase the probability that UK exporters settle for a third currency. In contrast, euro pegs ($Epeg^c = 1$) increase the probability that UK exporters settle for VCP relative to PCP.

The last factor I consider is *transaction cost of exchange*. Following Goldberg and Tille (2011), FX^c captures the share of the importer's currency in daily global foreign exchange market turnover, reported in the BIS Triennial Central Bank Survey in 2007.⁸¹ Higher values of FX^c capture lower transaction costs for the importer's currency, and hence LCP should be used more (Goldberg and Tille, 2011).⁸² The results shown in column (4) are in line with this argument.

3.4.4 Industry and Destination Characteristics

In column (4) I add two other factors relating to industry characteristics. The first one is *market competition*. Exporters of consumption goods may face higher local competition in the foreign market than exporters of intermediate goods. I use the

⁷⁹In the section of robustness check, I exclude trade with the US and this effect disappears. The coefficients on $CVGBP^c$ become positive and therefore support Hypothesis 1.

⁸⁰The various types of pegs are: (a) no separate legal tender; (b) pre announced peg or currency board arrangement; (c) pre announced horizontal band narrower than or equal to $\pm 2\%$ and (d) de facto peg.

⁸¹The data include 35 currencies in 2007. Currencies not listed in the survey are assigned zero shares.

⁸²The theory also predicts that a currency that is traded extensively has lower transaction costs and is more likely to be considered as a vehicle currency (Devereux and Shi, 2013). Also see Swoboda (1968) and Rey (2001), among others, for earlier work on the role of currencies as a medium of exchange.

BEC classification to define the end-use of goods. The set of variable $Class^k$ is defined at the 5-digit SITC level and consists of three dummy variables: Final or consumption ($ClassF^k$), intermediate ($ClassI^k$) and capital goods ($ClassC^k$). Due to local competition, final goods sold to consumers are more likely to be priced in LCP (Bacchetta and van Wincoop, 2003). The finding in column (4) suggests that final goods are more likely to be priced in PCP relative to VCP. The coefficient for LCP is not significant and therefore there is no evidence supporting the theoretical predictions for the role of market competition.⁸³

The other factor I consider is *substitutability of goods*. I use the Rauch (1999) index to distinguish differentiated from homogeneous goods.⁸⁴ The Rauch variable is defined at the 4-digit SITC level and is captured by three dummy variables: Walrasian ($RauchW^k$), reference-priced ($RauchR^k$) and differentiated goods ($RauchN^k$). Walrasian and referenced-priced goods are viewed as more substitutable than differentiated goods. In theory, LCP is used more for homogeneous goods because exporters have the incentive to stabilise prices in the currency of the customers, when demand is highly elastic (Bacchetta and van Wincoop, 2005). Similarly, Goldberg and Tille (2008) document a coalescing effect: when goods are more homogeneous, an exporter is more prone to choose the currency used most extensively by its competitors. The coefficients on the Rauch variables support the argument that differentiated goods are more often priced in PCP, particularly relative to VCP.

I also add industry and destination fixed effects. In Table 3.5 the industry fixed effects are at the SITC 1-digit level.⁸⁵ Destination fixed effects are for the US, China, East and South East Asia, Europe excluding EU, other American countries, and all other countries. These variables are all significant.

3.4.5 Other Regression Models

In order to provide some interpretations for the magnitude of the coefficients, I use two other regression models: binary logistic model and linear probability model. The dependent variable is dichotomous: whether a transaction is priced in non-sterling (nPCP=1) or sterling (nPCP=0).

Column (5) in Table 3.5 reports the estimated (average) marginal effects from

⁸³In the previous section, I show that final goods are more priced in LCP (in value) than intermediate goods. This evidence is not significant in the regression results. One explanation is that final goods transactions are on average larger (in value) than intermediate goods transactions. The other explanation is that final goods are shipped more frequently and this dimension is eliminated in data collapsing.

⁸⁴The Rauch classification of goods is originally constructed in Rauch (1999) and revised in 2007. I use the liberal rather than conservative classification.

⁸⁵Other industry effects considered are the SITC 5-digit level and the HS4 level. The results do not change qualitatively.

binary logistic regression. Column (6) reports the results from a linear probability model. Overall the estimates are consistent with the results from the MNL model. I interpret only the results relating to the use of imported inputs below.

Firstly, firms that use imported inputs are 8-14% more likely to use a foreign currency for exports than firms that do not use imported inputs. Secondly, a 1% increase in a firm's effective dependence on foreign inputs priced in the foreign currency ($InputPCP^{i,c}$) increases the probability of using a foreign currency by 9-12%. However, it is worth noting here that these two models do not separate the options of LCP and VCP. As shown in the results of MNL regressions, the variable $InputPCP^{i,c}$ has opposite effects for LCP and VCP (relative to PCP). The magnitude of the estimates would be higher if it is for the probability of using "the same" foreign currency (LCP) for exports. Lastly, a 1% increase in a firm's total share of inputs priced in sterling ($InputLCP^i$) increases the probability of using sterling by 17-18%.

Column (7) shows the results using a linear probability model with the full export dataset (2.54 millions). Overall the results predict the same directions as other specifications; however the magnitudes of the coefficients vary. These results therefore need to be interpreted with caution.

3.4.6 Robustness

I run a number of alternative regressions to ensure the robustness of the results. A subset of the results are reported in Table 3.6. I consider exclusively exporters that use imported inputs. Hence the variable $Import^i$ is dropped. Column (8) and (9) show that my findings remain virtually unchanged. In column (10) I consider importing firms in the manufacturing sectors only (SITC 6-8). In 2011, UK manufactured goods account for about 56% of total non-EU exports. The estimates remain robust.

In column (11) I consider a subsample with firms involving in back-and-forth trade, i.e. importing inputs from and exporting goods to the same country. Again the results remain robust.

As discussed in the previous section, the US is a special case where LCP is used extensively compared to other destinations. In column (12) I exclude the US from the sample and consider UK exports to non-US destinations only. The findings on the effects of imported inputs do not change qualitatively. Also, the coefficients on the variable $fiveyrol^i$ are both negative and significant. This evidence suggests that experienced firms exporting to non-US markets are more likely to use sterling than any other currency. The results on macroeconomic factors also differ from the previous analysis. In particular, the variable $CVGBP^c$ shows the same predicted effects as the variable $CVUSD^c$. High exchange rate volatility against

Table 3.6: Determinants of Currency Choice: Robustness Checks

Dependent Variable	(8)		(9)		(10)		(11)		(12)	
	Importing Firms		Importing Firms		Importing Firms Manufacturing		Firms with Back- and-forth Trade		Importing Firms Excluding US	
	LCP	VCP	LCP	VCP	LCP	VCP	LCP	VCP	LCP	VCP
Firm Characteristics										
<i>InputPCP^{i,c}</i>	0.27*** (0.03)	-1.62*** (0.08)	0.24*** (0.03)	-1.47*** (0.08)	0.25*** (0.03)	-1.55*** (0.08)	1.22*** (0.03)	-0.80*** (0.08)	2.21*** (0.08)	-1.81*** (0.12)
<i>InputLCPⁱ</i>	-0.40*** (0.04)	-1.12*** (0.05)	-0.43*** (0.05)	-1.11*** (0.04)	-0.48*** (0.04)	-1.15*** (0.04)	-0.62*** (0.04)	-1.93*** (0.06)	-0.30*** (0.04)	-1.16*** (0.06)
<i>ratio^{i,k}</i>	0.97*** (0.15)	0.74*** (0.15)	1.13*** (0.19)	0.71*** (0.15)	1.03*** (0.21)	0.67*** (0.19)	0.68*** (0.15)	0.53*** (0.16)	1.66*** (0.18)	0.68*** (0.15)
<i>fiveyrol^d</i>	0.01*** (0.03)	-0.15*** (0.02)	0.01 (0.03)	-0.16*** (0.03)	0.02 (0.03)	-0.17*** (0.03)	-0.03 (0.03)	-0.30*** (0.04)	-0.15** (0.05)	-0.17*** (0.03)
<i>Top10^k</i>	0.32*** (0.02)	0.08*** (0.02)	0.34*** (0.03)	0.09*** (0.02)	0.32*** (0.03)	0.08*** (0.03)	0.25*** (0.03)	0.01 (0.03)	0.41*** (0.04)	0.11*** (0.02)
Macroeconomic Factors										
<i>cvGBP^c</i>			7.35*** (0.38)	1.20*** (0.15)	7.60*** (0.41)	1.22*** (0.17)	7.96*** (0.41)	0.95*** (0.20)	-1.14*** (0.41)	-0.27** (0.12)
<i>cvUSD^c</i>			-1.73*** (0.34)	-0.31*** (0.11)	-2.22*** (0.41)	-0.24** (0.12)	-3.28*** (0.51)	-0.78*** (0.18)	-1.79*** (0.41)	-0.27** (0.11)
<i>Dpeg^c</i>			-1.18*** (0.08)	-0.04** (0.02)	-1.14*** (0.08)	-0.04** (0.02)	-1.13*** (0.08)	-0.03 (0.03)	-1.14*** (0.07)	-0.07** (0.02)
<i>Epeg^c</i>			-2.53*** (0.36)	0.30*** (0.05)	-2.37*** (0.38)	0.29*** (0.05)	-2.32*** (0.49)	0.53*** (0.07)	-2.44*** (0.36)	-0.27*** (0.04)
<i>FX^c</i>			0.04*** (0.00)	-0.02*** (0.00)	0.04*** (0.00)	-0.02*** (0.00)	0.03*** (0.00)	-0.02*** (0.00)	0.04*** (0.00)	-0.04*** (0.00)
Industry Characteristics										
<i>ClassC^k</i>			0.08** (0.04)	0.03 (0.06)	0.08 (0.04)	0.02 (0.06)	0.08** (0.04)	0.05 (0.04)	0.04 (0.09)	0.03 (0.06)
vs. Intermediate										
<i>ClassF^k</i>			-0.09 (0.08)	-0.55*** (0.08)	-0.17*** (0.06)	-0.56*** (0.08)	-0.27*** (0.06)	-0.55*** (0.09)	0.27 (0.14)	-0.54*** (0.08)
vs. Intermediate										
<i>RauchR^k</i>									0.60*** (0.18)	0.09 (0.08)
vs. Homogeneous										
<i>RauchN^k</i>									0.55*** (0.12)	0.08 (0.08)
vs. Homogeneous										
Constant	-0.95*** (0.19)	-2.86*** (0.27)	-4.27*** (0.08)	-0.65*** (0.05)	-4.83*** (0.39)	-0.39*** (0.08)	-7.04*** (0.40)	0.46*** (0.09)	-4.79*** (0.13)	-0.79*** (0.08)
Industry effects	Yes		Yes		Yes		No		No	
Destination effects	Yes		Yes		Yes		No		No	
Obs.	529,890		529,890		452,404		216,845		371,538	
Pseudo-R ²	0.158		0.163		0.170		0.211		0.141	

Notes: The default option is PCP. Industry effects are dummies for SITC 1-digit sectors. Destination effects are dummies for the US, China, East/SE Asia, Europe excluding EU, other American countries, and all other countries. Clustered standard errors in parentheses (at the HS4 level). * significant at 10%; ** significant at 5%; *** significant at 1%.

sterling makes PCP more appealing, a result consistent with Hypothesis 1. Furthermore, the coefficients on the exchange rate pegs variables all have significant negative signs. This implies that UK exporters are more likely to use sterling when exporting to countries with exchange rate pegs.⁸⁶

3.5 Currency Denomination in UK Imports

One challenge of relating imported inputs to currency denomination in imports is to measure systematically the dependence on imported inputs across exporters from different exporting countries. I use a measure of value added to gross exports (VAX ratio) computed by Johnson and Noguera (2012) to proxy for the dependence on imported inputs at the country and country-industry level. Countries with higher value added to gross exports are less dependent on imported inputs. VAX ratios are therefore inversely related to the dependence on imported inputs.

I take the full sample of UK imports from non-EU countries in 2011 (7.31 million transactions). The dependent variables are dummy variables capturing whether the pricing strategy is PCP, LCP or VCP. The regressions are estimated using a multinomial logit procedure (MNL), taking PCP as the default option. The estimating equation is:

$$\Pi^{c,k}(PCP) = \text{MNL} \left(VAX^c, Macro^c, Industry^k \right), \quad (3.12)$$

where VAX^c denotes the VAX ratios at the country level, $Macro^c$ is a set of macro-economic factors relating to exchange rates, and $Industry^k$ is a set of other measures at the industry level.

I control for within-industry correlation by clustering the standard errors at the HS4 level (1,206 clusters). For the sake of clarity, I only report a subset of results in Table 3.7 together with the associated Akaike Information Criteria (AIC) and Pseudo R-square statistics. The first column only includes constant terms. The positive and significant coefficients show unexplained prominent use of LCP and VCP (relative to PCP).

3.5.1 VAX Ratios

VAX ratios capture the share of value-added exports in total exports, ranging from 0 to 1.⁸⁷ In column (2) in Table 3.7, the two negative and significant coefficients

⁸⁶ Another robustness check is replacing the liberal version of the Rauch indexes with the conservative one. The results are not reported here but I do not find significance in the explanatory power of the conservative version of the Rauch indexes.

⁸⁷ Countries not included in Johnson and Noguera (2011) are assigned the regional average in the analysis.

Table 3.7: Currency Denomination in UK Imports

Dependent Variable	(1)		(2)		(3)		(4)		(5)	
	LCP(£)	VCP	LCP(£)	VCP	LCP(£)	VCP	LCP(£)	VCP	LCP(£)	VCP
<i>VAX^c</i>			-8.65*** (0.72)	-12.91*** (0.52)	-1.68** (0.73)	-3.30*** (0.15)	-1.67** (0.69)	-3.47*** (0.64)	-1.62** (0.71)	-3.44*** (0.60)
Macroeconomic Factors										
<i>cvGBP^c</i>					-5.36*** (1.76)	-8.12*** (1.33)	-6.64*** (0.23)	-8.15*** (0.27)	-6.89*** (1.63)	-8.33*** (1.33)
<i>Dpeg^c</i>					0.98*** (0.23)	1.86*** (0.27)	1.22*** (0.23)	1.68*** (0.27)	0.60*** (0.23)	1.66*** (0.27)
<i>Epeg^c</i>					1.11*** (0.35)	0.70** (0.30)	1.22*** (0.36)	0.71*** (0.29)	1.31*** (0.34)	0.72** (0.29)
<i>FX^c</i>					-0.05*** (0.00)	-0.07*** (0.00)	-0.05*** (0.00)	-0.08*** (0.00)	-0.05*** (0.00)	-0.07*** (0.00)
Industry Characteristics										
<i>ClassC^k</i>					-0.23 (0.23)	-0.37** (0.12)	-0.15 (0.17)	-0.27 (0.21)	-0.17 (0.26)	-0.21 (0.18)
vs. Intermediate										
<i>ClassF^k</i>					0.49*** (0.20)	-0.37 (0.15)	0.55*** (0.20)	-0.28 (0.15)	0.60*** (0.19)	-0.10 (0.16)
vs. Intermediate										
<i>Mktshare^{k,c}</i>							1.61** (0.39)	0.66 (0.42)	1.68*** (0.39)	0.68 (0.42)
<i>Impct^k</i>							0.27 (0.33)	-0.13 (0.28)	0.44 (0.33)	-0.10 (0.28)
<i>Top5^k</i>							-0.22** (0.08)	0.30*** (0.08)	-0.22*** (0.08)	0.30*** (0.08)
Constant	0.66*** (0.13)	0.62*** (0.09)	7.04*** (0.52)	9.89*** (0.37)	3.91*** (0.70)	5.60*** (0.54)	3.67*** (0.66)	5.65*** (0.55)	1.89*** (0.68)	4.62*** (0.74)
Industry effects									Yes	
Obs.(millions)		7.31		7.31		7.31		7.31		7.31
AIC		15,507,253		14,238,974		10,437,866		10,338,805		10,275,217
Pseudo-R ²		-		0.082		0.327		0.333		0.340

Notes: The default option is PCP. Industry effects are dummies for SITC 1-digit sectors. Clustered standard errors in parentheses (at the HS4 level). * significant at 10%; ** significant at 5%; *** significant at 1%.

show that high VAX ratios (low dependence on imported inputs) make PCP more likely. This result holds across columns, after controlling for other factors. This implies that countries more engaged in trade in intermediate goods use less of their own currencies for exports. I also use a further disaggregated VAX ratio series at the country-industry level, and the result still holds.⁸⁸

3.5.2 Other Findings

With regards to macroeconomic factors, the results again support Hypothesis 1 that exchange rate volatility makes PCP more appealing relative to LCP. Also,

⁸⁸Results are not reported. VAX ratios at the country-industry level are computed by Johnson and Noguera, including 93 countries, 19 regions and 57 sectors in GSC codes. These ratios are not published in their paper.

UK imports from countries with exchange rate pegs are more likely to be priced in sterling or a third currency (LCP or VCP). The effects for transaction costs in foreign exchange market are also significant.

In column (3) I also consider the BEC classification of goods. Imports of final goods are more priced in LCP relative to PCP compared to intermediate goods. This finding supports the theoretical predictions in Bacchetta and van Wincoop (2003).

Following Goldberg and Tille (2011), I also control for three other industry characteristics: (i) *market share of exporters* is captured by the variable $Mktshare^{k,c}$, which is the overall market share of all exporters from country c in all UK imports in industry k (at the HS4 level); (ii) *concentration of the importers* is captured by the variable $Impct^k$, which is the share of imports in industry k accounted for by the top 10 importers and (iii) *transaction size* is captured by a dummy variable $Top5^k$, taking the value one if a transaction falls in the top 5th percentile of sized transaction (in value) within any HS4 industry and zero otherwise.⁸⁹ The results are shown in column (4) and (5). Higher market shares of exporters make LCP more likely relative to PCP. The effects of $Impct^k$ are not significant. Also, the effects of transaction size differ for LCP and VCP.

3.6 Concluding Remarks

This paper documents the stylized facts from UK customs data which show large discrepancies in firms' choice of invoicing currency. UK firms that rely on imported inputs are less likely to use their home currency for exports. I view this as the main contribution of the paper. Although this finding is intuitive, it is important since it points to firm characteristics as a key determinant for currency denomination in international trade. Other important findings are that larger firms (in terms of market share of exports) are less likely to use PCP, while more experienced firms are more likely to use PCP.

The application of the VAX ratios computed by Johnson and Noguera (2012) in the content of invoicing currency is viewed as another empirical contribution. I show a systematic finding that countries and industries more dependent on imported inputs (with lower VAX ratios) tend to choose a currency other than their own for exports.

These finding have strong policy implications for the degrees of exchange rate pass-through because large variation in invoicing currency choice directly translates into large variation in pass-through. Currency choice is crucial to understand the

⁸⁹In Goldberg and Tille (2011) market share of exporters is a proxy for the bargaining power of exporters, while concentration of the importers represents the bargaining power of importers.

effects of exchange rate changes on trade balances well as domestic inflation. Moreover, exchange rate pass-through to import prices exhibits significant heterogeneity across industries. The manufacturing and raw materials sectors in the UK, for example, have much higher pass-through than the energy sector, in both the short and the long run (Mumtaz, Oomen and Wang, 2006).⁹⁰ It is therefore important to look into firm characteristics across industries in order to fully explain the heterogeneity of pass-through.

One limitation of the paper is not to account for intra-firm trade. Although some researchers have shown no potential difference in currency choice within and across firms (Friberg and Wilander, 2008), future analysis and firm evidence would further contribute to our understanding of the determinants of invoicing currency.

⁹⁰Their estimated average rates of pass-through are calculated with quarterly UK data from 1984 Q1 to 2004 Q1.

3.A Model Solutions

This appendix provides the detailed derivation for the model in Section 3.2.2. I drop the subscript i for brevity. Given output Y , the firm minimizes its total cost:

$$\min_{L,X,Z,M} \text{TC}(Y) = WL + QZ + SQ^*M + Wf.$$

Denote by μ and χ the Lagrange multiplier on constraints (3.2) and (3.3) respectively. The first-order conditions of cost minimization are:

$$\begin{aligned} W &= \mu(1-\gamma) \frac{Y}{L}, \\ \chi &= \mu\gamma \frac{Y}{X}, \\ Q &= \chi \left(\frac{X}{Z} \right)^{1/(1+\delta)}, \\ SQ^* &= \chi \left(\frac{a^\delta X}{M} \right)^{1/(1+\delta)}. \end{aligned}$$

Rearranging these conditions yields:

$$W = \mu(1-\gamma) \frac{Y}{L}, \tag{A-1}$$

$$QX = \mu\gamma Y \left(\frac{X}{Z} \right)^{1/(1+\delta)}, \tag{A-2}$$

$$\frac{SQ^*M}{QZ} = \left(\frac{a}{SQ^*/Q} \right)^\delta. \tag{A-3}$$

Substituting (A-3) into (3.3) we get $X = Z \left[1 + \left(\frac{a}{SQ^*/Q} \right)^\delta \right]^{(1+\delta)/\delta}$. Together with (A-2) we get:

$$QX = \mu\gamma Y \left[1 + \left(\frac{a}{SQ^*/Q} \right)^\delta \right]^{1/\delta}, \tag{A-4}$$

Substituting (A-4) and (A-1) into (3.2) we can solve for μ :

$$\mu = \frac{C}{Ab^\gamma}, \tag{A-5}$$

where $b \equiv \left[1 + \left(\frac{a}{SQ^*/Q} \right)^\delta \right]^{1/\delta}$ and $C = \gamma^{-\gamma} (1 - \gamma)^{\gamma-1} Q^\gamma W^{1-\gamma}$. Substituting (A-1), (A-2) and (A-3) into the total cost function yields:

$$TC(Y) = \mu Y + Wf, \quad (\text{A-6})$$

where μ is the marginal cost facing the firm.

Finally, the parameter ψ is defined as the fraction of total costs spent on imported inputs: $\psi = SQ^*M / (SQ^*M + QZ)$. Using (A-3) together with the expression for $SQ^*M = \gamma\mu Y (1 - b^{-\delta})$, I obtain the share of costs spent on imported inputs as:

$$\psi = (1 - b^{-\delta}). \quad (\text{A-7})$$

Some rearranging yields the home share of inputs in (3.5). It can also be shown that the partial elasticity of the marginal cost with respect to the exchange rate equals the import intensity:

$$\begin{aligned} \frac{\partial \ln \mu}{\partial \ln S} &= \frac{\partial \ln \mu}{\partial \ln b} \times \frac{\partial \ln b}{\partial \ln S} \\ &= (-\gamma) \left[- (1 - b^{-\delta}) \right] \\ &= \psi. \end{aligned} \quad (\text{A-8})$$

3.B Proof of Proposition 3

In this appendix I first provide a proof of Proposition 3. Following the solution technique of Devereux et al. (2004), I drop the subscript i for simplicity. From (3.6) and (3.8), the expected discounted profits under PCP are given as:

$$\begin{aligned} E\Pi^{PCP} &= \left(\frac{\lambda}{\lambda-1} \frac{E(\mu \cdot S^\lambda \Omega)}{E(S^\lambda \Omega)} \right)^{1-\lambda} E(S^\lambda \Omega) \\ &\quad - \left(\frac{\lambda}{\lambda-1} \frac{E(\mu \cdot S^\lambda \Omega)}{E(S^\lambda \Omega)} \right)^{-\lambda} E(\mu \cdot S^\lambda \Omega) \\ &= \tilde{\lambda} \left[E(S^\lambda \Omega) \right]^\lambda \left[E(\mu \cdot S^\lambda \Omega) \right]^{1-\lambda}, \end{aligned} \quad (\text{B-1})$$

where $\tilde{\lambda} = \frac{1}{\lambda-1} \left(\frac{\lambda}{\lambda-1} \right)^{-\lambda}$, $\Omega = \kappa P_{hf}^{*(\lambda-\theta)} P^{*\theta} C^*$. Note that the last line of (B-1) follows because prices are preset one period in advance, i.e., $E_{t-1}(P_t) = P_t$. This expression may also be rewritten as:

$$\tilde{\lambda} \{E[\exp(\lambda \ln S) \exp(\ln \Omega)]\}^\lambda \{E[\exp(\ln \mu) \exp(\lambda \ln S) \exp(\ln \Omega)]\}^{1-\lambda}. \quad (\text{B-2})$$

In the next step I take the second order approximation for the first term in brackets in (B-2):

$$\begin{aligned} E[\exp(\lambda \ln S) \exp(\ln \Omega)] &\approx \exp[\lambda E(\ln S)] \exp[E(\ln \Omega)] \\ &\times \left[1 + \frac{\lambda^2}{2} \text{var}(\ln S) + \frac{1}{2} \text{var}(\ln \Omega) + \lambda \text{cov}(\ln \Omega, \ln S) \right]. \end{aligned} \quad (\text{B-3})$$

Using the same approximation for $E[\exp(\ln \mu) \exp(\lambda \ln S) \exp(\ln \Omega)]$, I get an approximation for $E\Pi^{PCP}$ as follows:

$$\begin{aligned} &\Sigma \left[1 + \frac{\lambda^2}{2} \text{var}(\ln S) + \frac{1}{2} \text{var}(\ln \Omega) + \lambda \text{cov}(\ln \Omega, \ln S) \right]^\lambda \\ &\times \left[\begin{array}{c} 1 + \frac{1}{2} \text{var}(\ln \mu) + \frac{\lambda^2}{2} \text{var}(\ln S) + \frac{1}{2} \text{var}(\ln \Omega) \\ + \lambda \text{cov}(\ln \mu, \ln S) + \text{cov}(\ln \mu, \ln \Omega) + \lambda \text{cov}(\ln S, \ln \Omega) \end{array} \right]^{1-\lambda} \end{aligned} \quad (\text{B-4})$$

where $\Sigma = \tilde{\lambda} \exp[\lambda E(\ln S)] \exp[E(\ln \Omega)] \exp[(1-\lambda)E(\ln \mu)]$. Taking logs and using the approximation $\ln(1+x) \approx x$, the expected discounted profits thus become:

$$\begin{aligned} \ln E\Pi^{PCP} &\approx \ln \Sigma + \frac{\lambda^2}{2} \text{var}(\ln S) + \frac{1}{2} \text{var}(\ln \Omega) + \frac{1-\lambda}{2} \text{var}(\ln \mu) \\ &+ \left[\begin{array}{c} \lambda \text{cov}(\ln S, \ln \Omega) + \lambda(1-\lambda) \text{cov}(\ln \mu, \ln S) \\ + (1-\lambda) \text{cov}(\ln \mu, \ln \Omega) \end{array} \right]. \end{aligned} \quad (\text{B-5})$$

Now, from (3.7) and (3.9), the expected discounted profits under LCP are given as:

$$E\Pi^{LCP} = \tilde{\lambda} [E(S\Omega)]^\lambda [E(\mu \cdot \Omega)]^{1-\lambda}. \quad (\text{B-6})$$

Using the same approximation, this can be shown to be:

$$\begin{aligned} \ln E\Pi^{LCP} &\approx \ln \Sigma + \frac{\lambda}{2} \text{var}(\ln S) + \frac{1}{2} \text{var}(\ln \Omega) + \frac{1-\lambda}{2} \text{var}(\ln \mu) \\ &+ [\lambda \text{cov}(\ln S, \ln \Omega) + (1-\lambda) \text{cov}(\ln \mu, \ln \Omega)]. \end{aligned} \quad (\text{B-7})$$

Now, comparing (B-5) and (B-7) yields:

$$\begin{aligned}
\ln E\Pi^{PCP} - \ln E\Pi^{LCP} &= \frac{1}{2}var(\ln S) - cov(\ln \mu, \ln S) \\
&= \frac{1}{2}var(\ln S) + \gamma cov(\ln b, \ln S) \\
&= \frac{1}{2}var(\ln S) - \frac{\gamma}{\delta} cov(\ln(1 - \psi), \ln S). \quad (\text{B-8})
\end{aligned}$$

The second line comes from the equation for marginal cost in (3.4) and the third line comes from the home share of inputs in (3.5). The firm's decision rule in Proposition 3 follows.

The model also accommodates the cases of perfect substitutes and perfect complements between domestic and foreign inputs. When domestic and foreign inputs are perfect substitutes ($\delta \rightarrow \infty$), whether firms use imported inputs or not depends on the price-adjusted productivity term, $a_i/(SQ^*/Q)$. If a firm has an advantage in using imported inputs ($a_i/(SQ^*/Q) > 1$), then the firm uses imported inputs only. In this case, the right hand side of the decision rule in (3.10) becomes $var(\ln S)$ and the firm uses LCP only. On the contrary, if a firm has no advantage in using imported inputs ($a_i/(SQ^*/Q) < 1$), then the firm uses domestic inputs only. In this case, the right hand side of the decision rule in (3.10) becomes zero and the firm uses PCP only. If the price-adjusted productivity is unity, the firm is indifferent between varieties of inputs and also indifferent between currencies.

When domestic and foreign inputs are perfect complements ($\delta \rightarrow 0$), firms use both varieties and are indifferent between currencies.

3.C Currency Choice with the Option of VCP

This section extends the model of Devereux et al. (2004) to allow for the case of vehicle currency pricing (VCP). I consider a three-country environment where country C is the vehicle currency country. Firm i in country A (Home) sells a differentiated good to country B (Foreign) and faces a CES demand curve:

$$T(p^i) = \left(\frac{p^i}{P_h^*}\right)^{-\lambda} \left(\frac{P_h^*}{P^*}\right)^{-\theta} C^*,$$

where T is the quantity demanded, p_i is the firm's price, P_h^* is the price index for all home goods sold in the foreign country and P^* is the foreign consumer price index (all denominated in the vehicle currency). C^* is the foreign demand shifter that is independent of prices. Parameter λ is the elasticity of substitution across varieties and $\lambda > 1$. Parameter θ is the foreign elasticity of demand for domestic goods.

The firm pre-sets prices and invoicing currency one period in advance. The

expected discounted profits for PCP/LCP/VCP are:

$$\begin{aligned}
 E\Pi^{PCP} &= E \left[\kappa \left(p^{PCP(i)} - \mu_i \right) \left(\frac{p^{PCP(i)}}{S_{AC}P_h^*} \right)^{-\lambda} \left(\frac{P_h^*}{P^*} \right)^{-\theta} C^* \right], \\
 E\Pi^{LCP} &= E \left[\kappa \left(S_{AB}P^{LCP(i)} - \mu_i \right) \left(\frac{p^{LCP(i)}}{S_{BC}P_h^*} \right)^{-\lambda} \left(\frac{P_{AB}^*}{P^*} \right)^{-\theta} C^* \right], \\
 E\Pi^{VCP} &= E \left[\kappa \left(S_{AC}P^{VCP(i)} - \mu_i \right) \left(\frac{p^{VCP(i)}}{P_h^*} \right)^{-\lambda} \left(\frac{P_{AB}^*}{P^*} \right)^{-\theta} C^* \right],
 \end{aligned}$$

where μ is the marginal cost denominated in the home currency, S_{AC} is the exchange rate between currencies A and C (home currency price of the vehicle currency price), S_{BC} is the exchange rate between currency B and C (foreign currency price of the vehicle currency price).

The optimal prices which maximise the expected discounted profits, under PCP, LCP and VCP, respectively, can be derived as follows:

$$\begin{aligned}
 p^{PCP(i)} &= \frac{\lambda}{\lambda-1} \cdot \frac{E(\mu\Omega S_{AC}^\lambda)}{E(\Omega S_{AC}^\lambda)}, \\
 p^{LCP(i)} &= \frac{\lambda}{\lambda-1} \cdot \frac{E(\mu\Omega S_{BC}^\lambda)}{E(\Omega S_{AC} S_{BC}^{\lambda-1})}, \\
 p^{VCP(i)} &= \frac{\lambda}{\lambda-1} \cdot \frac{E(\mu\Omega)}{E(\Omega S_{AC})},
 \end{aligned}$$

where $\Omega = \kappa P_h^{*(\lambda-\theta)} P^{*\theta} C^*$.

Using these optimal prices, the expressions for expected discounted profits become:

$$\begin{aligned}
 E\Pi^{PCP} &= \tilde{\lambda} \left[E(\Omega S_{AC}^\lambda) \right]^\lambda \left[E(\mu\Omega S_{AC}^\lambda) \right]^{1-\lambda} \\
 E\Pi^{LCP} &= \tilde{\lambda} \left[E(\Omega S_{AC} S_{BC}^{\lambda-1}) \right]^\lambda \left[E(\mu\Omega S_{BC}^\lambda) \right]^{1-\lambda} \\
 E\Pi^{VCP} &= \tilde{\lambda} \left[E(\Omega S_{AC}) \right]^\lambda \left[E(\mu\Omega) \right]^{1-\lambda}
 \end{aligned}$$

where $\tilde{\lambda} = \frac{1}{\lambda-1} \left(\frac{\lambda}{\lambda-1} \right)^{-\lambda}$.

Using the second-order approximations for $E\Pi^{PCP}$, $E\Pi^{LCP}$, and $E\Pi^{VCP}$ and then taking logs, I obtain:

$$\begin{aligned} \ln E\Pi^{PCP} \approx & \ln \Sigma + \frac{1}{2} \text{var}(\ln \Omega) + \frac{1-\lambda}{2} \text{var}(\ln \mu) + \frac{\lambda^2}{2} \text{var}(\ln S_{AC}) \\ & + \left[\begin{aligned} & \lambda \text{cov}(\ln \Omega, \ln S_{AC}) + (1-\lambda) \text{cov}(\ln \mu, \ln \Omega) \\ & + \lambda(1-\lambda) \text{cov}(\ln S_{AC}, \ln \mu_i) \end{aligned} \right], \end{aligned} \quad (\text{C-1})$$

$$\begin{aligned} \ln E\Pi^{LCP} \approx & \ln \Sigma + \frac{1}{2} \text{var}(\ln \Omega) + \frac{1-\lambda}{2} \text{var}(\ln \mu) \\ & + \frac{\lambda}{2} \text{var}(\ln S_{AC}) + \frac{\lambda(1-\lambda)}{2} \text{var}(\ln S_{BC}) \\ & + \left[\begin{aligned} & \lambda \text{cov}(\ln \Omega, \ln S_{AC}) + (1-\lambda) \text{cov}(\ln \mu, \ln \Omega) \\ & + \lambda(1-\lambda) \text{cov}(\ln S_{BC}, \ln \mu) - \lambda(1-\lambda) \text{cov}(\ln S_{AC}, \ln S_{BC}) \end{aligned} \right], \end{aligned} \quad (\text{C-2})$$

$$\begin{aligned} \ln E\Pi^{VCP} \approx & \ln \Sigma + \frac{1}{2} \text{var}(\ln \Omega) + \frac{1-\lambda}{2} \text{var}(\ln \mu) + \frac{\lambda}{2} \text{var}(\ln S_{AC}) \\ & + [\lambda \text{cov}(\ln \Omega, \ln S_{AC}) + (1-\lambda) \text{cov}(\ln \mu, \ln \Omega)], \end{aligned} \quad (\text{C-3})$$

where $\Sigma = \tilde{\lambda} \exp[(1-\lambda) E \ln \mu] \exp[\lambda E \ln S_{AC}] \exp[E \ln \Omega]$.

By comparing (C-1) and (C-3), we can get $E\Pi^{VCP} > E\Pi^{PCP}$ if and only if:

$$\text{cov}(\ln S_{AC}, \ln \mu) - \frac{1}{2} \text{var}(\ln S_{AC}) > 0. \quad (\text{C-4})$$

By comparing (C-2) and (C-3), we can get $E\Pi^{VCP} > E\Pi^{LCP}$ if and only if:

$$\frac{1}{2} \text{var}(\ln S_{BC}) + \text{cov}(\ln S_{BC}, \ln \mu) - \text{cov}(\ln S_{AC}, \ln S_{BC}) > 0. \quad (\text{C-5})$$

Firm's Decision Rule

Combining (C-4) and (C-5) we get the firm's decision rule. The firm in country A sets its price in the vehicle currency if and only if:

$$\begin{aligned} \frac{1}{2} \text{var}(\ln S_{BC}) + \text{cov}(s_{BC}, \ln \mu_i) - \text{cov}(\ln S_{AC}, \ln S_{BC}) & > 0 \quad \text{and} \\ \text{cov}(\ln S_{AC}, \ln \mu_i) - \frac{1}{2} \text{var}(\ln S_{AC}) & > 0. \end{aligned} \quad (\text{C-6})$$

In this condition, the covariance between two exchange rates vis-à-vis the vehicle currency is a new element compared to a two-country setting. If the covariance between two existing exchange rates vis-à-vis the vehicle currency is negative, firms are more inclined to choose VCP. The condition also says that a more volatile exchange rate between countries B and C would lead the firm in country A to set its price in the vehicle currency rather than currency B. A more volatile exchange rate between countries A and C, on the other hand, would discourage the firm to set its price in the vehicle currency.

Chapter 4

Gravity with Trade in Intermediate Goods

4.1 Introduction

The gravity model has experienced great success in explaining the effects of the distance-related factors on bilateral trade flows. These include national borders, tariff and non-tariff barriers, trade costs, as well as non-economic factors such as cultural and language differences. A micro-founded framework pioneered by Anderson and van Wincoop (2003, henceforth A-vW) is now widely used as the standard gravity formulation and tested empirically. Due to the broad nature of the gravity equation, a good amount of subsequent research has attempted to estimate the proxies for the variables in the equation, in particular trade costs, to explain gross trade flows. A scholarly consensus is that gravity-type equations are empirically evident.⁹¹

Much less attention, however, has been given to an empirical regularity, namely trade in intermediate goods or back-and-forth trade, in the gravity literature. Intuitively, if any country is involved in back-and-forth trade with another, gross trade flows overstate the actual demand and supply in both countries. When countries are involved in vertical specialisation where production process goes through more than two countries, there exists a hidden structure of trade underlying the gross trade flows.⁹² This paper asks how underlying trade structure alters the predictions and performances of the gravity models.

Gravity equations for gross trade can be derived from a number of trade models such as Krugman (1979), Eaton and Kortum (2002) and Melitz (2003). Some

⁹¹See Brakman and van Bergejik (2010), for example, for the history of the gravity model.

⁹²See Hummels, Ishii and Yi (2001) for the definition. Also, Feenstra (1998) for a survey of the 1990s literature on the disintegration of production.

scholars have also considered the cross-border intermediate input linkages.⁹³ The main focus of the paper, however, is more closely related to studies which argue that the economic mass variables such as country GDPs fail to be good proxies when trade in intermediate goods is important. Bergstrand and Egger (2010) and Baldwin and Taglioni (2011), for example, show similar results that the standard gravity variables perform well on a huge database consisting of a wide range of countries.⁹⁴ As Baldwin and Taglioni (2011) point out, this is because the pattern of trade in intermediate goods is proportional to trade in final goods, especially for trade among the developed countries. When testing the standard gravity equation on a subsample of the factory Asian countries, however, Baldwin and Taglioni (2011) report a relatively poor performance.⁹⁵ The conjecture is that these Asian countries are more involved in trade in intermediate goods. To explore it more systematically, they propose a modified gravity equation that includes an additional independent variable: the share of bilateral imports that is in intermediates, and test it on bilateral trade between pairs of 187 countries. Their results show that the economic mass variables (i.e. GDP) in gravity equation fail to be good proxies when trade in intermediate goods are more dominant.

This paper analyses gravity equations incorporating trade in intermediate goods and identify the gravity predictions that are similar to or different from models with final goods only. I start with an accounting exercise showing that even without trade in intermediate goods, gravity models over-predict trade volume in the presence of (domestically produced) intermediate goods. More interestingly, trade in intermediate goods actually helps mitigate such effect. Another important implication is that the standard gravity model predicts a lower amount of trade for smaller importing countries.

In the main analysis I build a theoretical framework with differentiated intermediate and final goods and discuss the model predictions in the form of gravity equations. The model is based on Krugman (1979) with complete specialisation and monopolistic competition.⁹⁶ The model differs from Baldwin and Taglioni (2011) in allowing for different elasticities of substitution between final and intermediate goods-sectors.⁹⁷ This distinction is crucial for examining sectoral differences in the

⁹³Noguera (2012), for example, derives an approximation of the gravity equation for value-added trade based on Anderson and van Wincoop (2003).

⁹⁴Both studies adopt the classification of UN Broad Economic Categories (BEC).

⁹⁵The Factory Asia countries include Japan, Indonesia, Korea, Malaysia, Philippines, Thailand and Taiwan.

⁹⁶Complete specialisation and monopolistic competition are not the only structures compatible with a gravity model. See, for instance, Baier and Bergstrand (2001) for a list of exceptions and Haveman and Hummels (2004) for the implications of incomplete specialisation for gravity equation.

⁹⁷Ethier (1982) extended Krugman (1979) to incorporate differentiated intermediate goods, but final goods are homogeneous. In his framework all trade is in intermediates. Krugman and Venables (1995) allow for both differentiated intermediate and final goods. However, the focus is on

predictions of gravity models.

The first finding of the model is that there are gains from trade for both trade in intermediate goods and final goods. The degree depends on the elasticities of substitution and the production function parameters. I then derive gravity equations for trade in both types of goods separately. I also derive the bilateral value-added ratio (VAX ratio), proposed by Johnson and Noguera (2012).

The main contribution of the paper is to relate gravity equations to labour shares of income. The model results show that labour shares of income enter the two gravity equations with different signs. Moreover, the weighted average on labour share of income in the importing country and the exporting country also enter the equations with different signs. Similar results are found for the bilateral VAX ratio. This is because in the model, high labour share of income in the exporting country implies large intermediate goods sector (which uses labour only). The same parameter for the importing country, however, captures higher income spent on final goods. Given that the parameter is industry-specific, the implication of these results is that it is crucial to take it into account when analysing the effects of industry-specific factors on bilateral trade flows.

The paper is structured as follows. The next section sets out a simple accounting exercise to show trade predictions in a frictionless world with trade in intermediate goods. Section 4.3 presents the main analysis of the gravity predictions when there is trade in intermediate goods. Section 4.4 concludes.

4.2 Gravity and Trade in Intermediate Goods

4.2.1 Frictionless Gravity Model

I begin by providing a simple model closely related to the standard A-vW gravity equation based upon the properties of expenditure systems. Here I assume away trade barriers and note that production is completely specialised.⁹⁸ In what follows, C denotes consumption, Y is gross output as well as income (real GDP), and T is volume of trade. Assuming balanced trade and identical and homothetic preferences, the bilateral volume of trade from country i to j (T_{ij}) is:

$$T_{ij} = \theta_j Y_i, \quad (4.1)$$

where $\theta_j = Y_j/Y_w$ denotes the fraction of j 's income spent on country i 's product. Rearranging (4.1) gives a prediction for bilateral trade:

geographical allocation of firms and wage differences across industries, instead of bilateral volume of trade concerning gravity studies.

⁹⁸For simplicity, the varieties of goods are defined symmetrically. A variety index is therefore dropped.

$$T_{ij} = \frac{Y_i Y_j}{Y_w} = T_{ji}. \quad (4.2)$$

This equation is the well-known frictionless gravity model. Summing (4.2) over all i 's trade partners, we get i 's total exports, or the multilateral volume of trade:

$$T_i = \sum_{j \neq i} T_{ij} = \sum_{j \neq i} \frac{Y_i Y_j}{Y_w} = Y_i (1 - \theta_i). \quad (4.3)$$

This equation implies the trade share of income (T/Y) is decreasing in a country's share of world income (θ).

4.2.2 Trade in Intermediate Goods

In this section I present a simple accounting exercise to derive the predictions for the volume of trade in the presence of intermediate goods. As above, trade is costless and production is completely specialised. Without introducing preferences and technology, I assume the consumption share (in final goods) is simply its production share in world output. With the use of intermediate goods, it is important to distinguish gross output from income. In what follows, Y denotes gross output (in value) and I denotes income (GDP). Also, superscripts M denote intermediate goods and C final goods. Assume countries differ in relative sizes of the two production sectors. In country i , a production share α_i is in final goods:

$$Y_i^C = \alpha_i Y_i, \quad (4.4)$$

and the rest $1 - \alpha_i$ is in intermediate goods:

$$Y_i^M = (1 - \alpha_i) Y_i. \quad (4.5)$$

Assuming identical and homothetic preferences, country j demands a fraction γ_{ij}^C of i 's production in final goods:

$$T_{ij}^C = \gamma_{ij}^C Y_i, \quad (4.6)$$

where $\gamma_{ij}^C \equiv \alpha_i (Y_j/Y_w)$ is the product of i 's production share in final goods and j 's share in world total production. Similarly, country j demands a fraction γ_{ij}^M of i 's production in intermediate goods:

$$T_{ij}^M = \gamma_{ij}^M Y_i, \quad (4.7)$$

where γ_{ij}^M depends on the production function and demand structure which will be introduced in the next section.

Market clearing conditions yield:

$$\begin{aligned}\alpha_i Y_i &= \sum_j \gamma_{ij}^C Y_i, \\ (1 - \alpha_i) Y_i &= \sum_j \gamma_{ij}^M Y_i,\end{aligned}\tag{4.8}$$

which imply all country i 's output must be either consumed domestically or bought by foreign importers.⁹⁹

Rewriting γ_{ij}^C as a function of θ_j (j 's world output share) gives:

$$\gamma_{ij}^C \equiv \alpha_i \left(\frac{Y_j}{Y_w} \right) = \alpha_i \theta_j.\tag{4.9}$$

Using (4.6)-(4.9), we can solve the bilateral volume of trade:

$$\begin{aligned}T_{ij} &= T_{ij}^C + T_{ij}^M \\ &= \frac{Y_i Y_j}{Y_w} \left[\alpha_i + \frac{\gamma_{ij}^M}{\theta_j} \right].\end{aligned}\tag{4.10}$$

Equation (4.10) shows the gravity prediction with the presence of intermediate goods. When all goods are finals, $\alpha_i = 1$ and $\gamma_{ij}^M = 0$. Equation (4.10) reduces to the simple frictionless gravity model, equation (4.2).¹⁰⁰ Therefore, the first term in equation (4.10), $Y_i Y_j / Y_w$, captures the maximum level of trade in a frictionless world with final goods only.

The term in brackets shows two opposite forces affecting the performance of the gravity model. The first term in the brackets is the consumption trade effect. If any production is used as intermediate goods (regardless of the destination), $\alpha_i < 1$, we expect lower trade volume as opposed to the standard frictionless case. This speaks to the argument that standard gravity models tend to over-predict trade volumes.¹⁰¹ Put differently, even if countries trade final goods only (i.e. the second term in the brackets can be dropped), this effect still exists with the use of domestically produced intermediate goods in production.¹⁰²

⁹⁹From (4.4) and (4.6), $Y_i^C = \sum_j T_{ij}^C = \sum_j \gamma_{ij}^C Y_i = (Y_i^C / \alpha_i) \sum_j \gamma_{ij}^C$. This gives $\alpha_i = \sum_j \gamma_{ij}^C$. From (4.5) and (4.7), $Y_i^M = \sum_j T_{ij}^M = Y_i \sum_j \gamma_{ij}^M = (1 - \alpha_i) Y_i$. This gives $1 - \alpha_i = \sum_j \gamma_{ij}^M$.

¹⁰⁰In a frictionless world, gross output equates gross value added if there is no trade in intermediate inputs, and also equates country GDP (because of no tax or subsidies).

¹⁰¹In particular, studies in favour of incomplete specialisation find similar results. See, for example, Haveman and Hummels (2004).

¹⁰²Other interpretations of this effect might include non-tradable goods and the degree of incomplete specialisation.

The second term in the brackets shows that trade in intermediate goods actually mitigates the first effect and helps improve the bilateral trade prediction of gravity models ($\gamma_{ij}^M > 0$). The general conjecture that trade in intermediate goods implies a higher trade volume does not necessarily hold. This depends on whether the second effect outweighs the first one. Another interpretation is that even if both production and trade in intermediate goods are proportional to total output (γ_{ij}^M and α_i fixed), the standard gravity model predicts a lower amount of trade for smaller importing countries (i.e. neglecting a small θ_j in the model underestimates the trade volume).

Equation (4.10) also provides some insight on the income elasticity of trade. It is well-known that income elasticity in the standard gravity model is unity. This is only true in equation (4.10) if the term in brackets is uncorrelated with incomes.

4.3 The Theoretical Framework

The market structure of this model is based upon Krugman (1979) with complete specialisation and increasing returns to scale in both intermediate and final goods sectors. The gravity equation is closely related to Anderson and van Wincoop (2003).

4.3.1 Consumers and Import Demand for Final Goods

The representative consumer in each country maximises a constant-elasticity-of-substitution (CES) utility function subject to a budget constraint where prices of the imported products reflect iceberg trade costs. Demand in final goods follows a CES structure with the elasticity of substitution σ , with $\sigma > 1$. Utility maximisation yields country j 's import demand for i 's final goods:

$$T_{ij}^C = \left(\frac{p_{ij}}{P_j} \right)^{1-\sigma} E_j^C, \quad (4.11)$$

where E_j^C is j 's total expenditure on consumption goods, $P_j = \left(\sum_i p_{ij}^{1-\sigma} \right)^{1/(1-\sigma)}$ is the standard Dixit-Stiglitz price index, and $p_{ij} = t_{ij}p_i$ is the price facing j 's consumers inclusive of the trade cost t_{ij} , with $t_{ij} > 1$. This equation also represents the domestic demand function when $i = j$, for which $t_{ij} = 1$.

4.3.2 Production and Import Demand for Intermediate Goods

I assume all firms produce both intermediate and final goods. They cannot enter or exit only one market. Therefore, the number of firms in any country is also the

number of varieties it offers for both goods.¹⁰³ Labour is assumed mobile across sectors, but immobile across countries.

Production in intermediate goods uses labour only with a linear cost function:

$$l_i^M = f + v y_i^M, \quad (4.12)$$

where l_i^M denotes labour input used in intermediate sector, $y_i^M = Y_i^M / n_i$ is the representative firm's market share in intermediate goods. f is the fixed cost and v the variable (marginal) cost. The total cost function is given by:

$$C_i(y_i^M) = w_i (f + v y_i^M), \quad (4.13)$$

where w_i is the wage.

Final goods in each country are produced by combining local labour inputs with a bundle of intermediate goods from all countries. Define z_i as the input combination:

$$z_i \equiv (l_i^C)^{1-\gamma} x_i^\gamma, \quad (4.14)$$

where l_i^C denotes domestic labour input, and $x_i = \left(\sum_j x_{ji}^{(\delta-1)/\delta} \right)^{\delta/(\delta-1)}$ is the bundle of intermediate inputs from all countries j . δ is the elasticity of substitution, with $\delta > 1$. Parameter γ is the input share associated with the corresponding intermediate bundle, with $0 < \gamma < 1$. Also, z_i follows a linear cost function:

$$z_i = F + V y_i^C, \quad (4.15)$$

where F is the fixed cost and V the variable (marginal) cost, and $y_i^C = Y_i^C / n_i$ is the firm's market share in final goods.

Firms' import demand for intermediate goods also follows a CES demand. Country j 's import demand for i 's intermediate inputs is:

$$T_{ij}^M = \left(\frac{q_{ij}}{Q_j} \right)^{1-\delta} E_j^M, \quad (4.16)$$

where E_j^M is j 's total expenditure on intermediate inputs, $Q_j = \left(\sum_i q_{ij}^{1-\delta} \right)^{1/(1-\delta)}$ is the input price index of the intermediate bundle, and $q_{ij} = t_{ij} q_i$ is the price facing j 's firms inclusive of the trade cost. Also, I assume identical trade costs for both goods, and symmetric trade costs between country pairs: $t_{ij} = t_{ji}$.

¹⁰³This setting implies when the number of firms increases, production chain also gets more fragmented because firms use more (differentiated) intermediate inputs for producing final goods.

4.3.3 Equilibrium and Gains from Trade

a) Pricing and Output

For intermediate goods sector, two conditions characterise equilibrium in the model. Firstly, profit maximisation ensures that prices are a markup over marginal costs in this class of model:

$$q_i = \left(\frac{\delta}{\delta - 1} \right) v w_i. \quad (4.17)$$

Secondly, under monopolistic competition firms earn zero profit which implies:

$$y_i^M = \frac{f}{v} (\delta - 1). \quad (4.18)$$

Therefore, the firm's market share of intermediate output is determined parametrically by the cost and factor demand functions.

Similarly, for final goods sector profit maximisation ensures the prices are a markup over marginal costs:

$$p_i = \left(\frac{\sigma}{\sigma - 1} \right) V \varphi w_i^{1-\gamma} Q_i^\gamma, \quad (4.19)$$

where $\varphi \equiv \gamma^{-\gamma} (1 - \gamma)^{\gamma-1}$, and firms take the input price index Q_i as given. Under monopolistic competition firms earn zero profit, and the condition yields:

$$y_i^C = \frac{F}{V} (\sigma - 1). \quad (4.20)$$

Similarly, the firm's market share of final output is determined parametrically by the cost and demand functions.

b) Labour Market Equilibrium, Relative Sector Sizes and Equilibrium Number of Firms

I first define output, expenditure and labour shares for both sectors in Table 4.1.

Table 4.1: Output, Expenditure and Labour Shares

	Intermediate Goods Sector	Final Goods Sector
Output	$Y_i^M / Y_i \equiv 1 - \alpha_i$	$Y_i^C / Y_i \equiv \alpha_i$
Expenditure	$E_i^M / Y_i \equiv 1 - \tau_i$	$E_i^C / Y_i \equiv \tau_i$
Labour	$L_i^M / \bar{L}_i \equiv 1 - \lambda_i$	$L_i^C / \bar{L}_i \equiv \lambda_i$

Country i has fixed labour endowment $\bar{L}_i = L_i^M + L_i^C$ and in equilibrium there

is full employment. Solving for relative sector size in outputs gives:

$$\begin{aligned}\frac{Y_i^M}{Y_i^C} &= \frac{1 - \alpha_i}{\alpha_i} = \frac{f/v}{F/V} \frac{\delta - 1}{\sigma - 1}, \text{ or} \\ \alpha_i &= \left(1 + \frac{f/v}{F/V} \frac{\delta - 1}{\sigma - 1}\right)^{-1}.\end{aligned}\quad (4.21)$$

Relative sector size in intermediate relative to final outputs depends on the costs and elasticities.

Solving for relative share of expenditures and rewriting it in terms of α gives:

$$\begin{aligned}\frac{E_i^M}{E_i^C} &= \frac{1 - \tau_i}{\tau_i} = \frac{\alpha_i \gamma}{1 - \alpha_i \gamma}, \text{ or} \\ \tau_i &= 1 - \alpha_i \gamma.\end{aligned}\quad (4.22)$$

Relative share of expenditures depends on the input share on intermediate goods in production (γ) and the share of final goods in outputs (α). Note that the expenditure on intermediate goods is proportional to output in finals. Therefore when the share of final goods in outputs increases (higher α), there is higher expenditure on intermediate goods (lower τ).¹⁰⁴ Another interpretation of τ is the "weighted" average of labour share of income. Labour share of income is unity in intermediate goods sector and $1 - \gamma$ in final goods sector. τ is the weighted average labour share of income, with each sector weighted by its output share.¹⁰⁵

Solving for relative sector size in labour and rewriting it in terms of α gives:

$$\begin{aligned}\frac{L_i^M}{L_i^C} &= \frac{1 - \lambda_i}{\lambda_i} = \frac{1}{1 - \gamma} \frac{1 - \alpha_i}{\alpha_i}, \text{ or} \\ \lambda_i &= \left(1 + \frac{1}{1 - \gamma} \frac{1 - \alpha_i}{\alpha_i}\right)^{-1}.\end{aligned}\quad (4.23)$$

Relative sector size in labour also depends on γ and α . Higher input share on intermediate goods in production (γ) leads to larger relative sector size in labour. However, when the share of final goods in outputs (α) increases, the allocation of labour is shifted towards the final goods sector.

Wages relative to input price index can also be solved, using cost functions and relative sector sizes:

¹⁰⁴That is, $E_i^M = \gamma Y_i^C$. Expenditure on consumption equals country GDP ($E_i^C = w_i \bar{L}_i$). Empirically, τ rarely varies for country aggregate data. Take Canada for example, the GDP/gross output ratio has been around 0.53-0.54 since 2001. However, τ exhibits significant sectoral heterogeneity.

¹⁰⁵ $(Y_i^M/Y_i) \times 1 + (Y_i^C/Y_i) \times (1 - \gamma) = \tau$.

$$\frac{w_i}{Q_i} = \gamma^{-1} (1 - \gamma)^{1-1/\gamma} \left(\frac{1 - \alpha_i}{\alpha_i} \frac{F\sigma}{f\delta} \right)^{1/\gamma}. \quad (4.24)$$

The equilibrium number of firms can be shown as:

$$n_i = \frac{\bar{L}_i}{f\delta} \left(\frac{1 - \alpha_i}{1 - \gamma\alpha_i} \right). \quad (4.25)$$

The equilibrium number of firms is larger with higher labour endowment, higher input share on intermediate goods in production and lower share of final goods in outputs.

c) Equilibrium Wages

To see how wages are solved, take labour income in final goods sector which equals labour's share $(1 - \gamma)$ in final goods production.

$$\begin{aligned} w_i L_i^C &= (1 - \gamma) Y_i^C \\ &= (1 - \gamma) \sum_j \pi_{ij}^C E_j^C, \end{aligned} \quad (4.26)$$

where $\pi_{ij}^C = \left(\frac{t_{ij} p_i}{P_j} \right)^{1-\sigma}$ is the income share of j spent on i 's final goods, corresponding to the CES demand structure. The second equation is the market clearing condition with the sum of country i 's total exports in final goods around the world, including its sales at home.

Labour income in intermediate goods sector is country i 's total gross output in intermediate goods (as labour is the only production factor), which is also country i 's total exports in intermediate goods around the world, including its sales at home:

$$\begin{aligned} w_i L_i^M &= Y_i^M \\ &= \sum_j \pi_{ij}^M E_j^M, \end{aligned} \quad (4.27)$$

where $\pi_{ij}^M = \left(\frac{t_{ij} q_i}{Q_j} \right)^{1-\delta}$ is the income share of j spent on i 's intermediate goods, corresponding to the CES demand structure.

Combining labour market equilibrium conditions (4.26) and (4.27), together with (4.21)-(4.23) yields:

$$\begin{aligned}
w_i \bar{L}_i &= \sum_j [\pi_{ij}^M E_j^M + (1 - \gamma) \pi_{ij}^C E_j^C] \\
&= \sum_j w_j \bar{L}_j \left[\frac{\alpha_i \gamma}{1 - \alpha_i \gamma} \pi_{ij}^M + (1 - \gamma) \pi_{ij}^C \right]. \tag{4.28}
\end{aligned}$$

When there is no intermediate goods, $\gamma = 0$, equation (4.28) reduces to $w_i \bar{L}_i = \sum_j \pi_{ij} w_j \bar{L}_j$. In this case, country i 's gross output (also GDP, which equals to $w_i \bar{L}_i$) is a weighted sum of all countries' gross outputs (including itself), weighted by the income share spent on i 's exports.¹⁰⁶ In equation (4.28), the term in brackets captures the adjusted weights assigned to every country with the presence of intermediate goods.

In order to solve wages we need to solve equilibrium prices, trade shares, together with (4.28) simultaneously. In the next subsection I illustrate the model with two special cases, in autarky and a frictionless world.

d) Wages in Special Cases: Autarky and Frictionless World

In Autarky, $\alpha_i = \tau_i$ and $\pi_{ii}^M = \pi_{ii}^C = 1$ for country i . Also, $q_i = Q_i$ and $p_i = P_i$.¹⁰⁷ Using the equilibrium price equations it is easy to show the real wage in autarky, denoted as w_i^A :

$$\begin{aligned}
w_i^A &\equiv \frac{w_i}{P_i} \\
&= \gamma^\gamma (1 - \gamma)^{1-\gamma} \left(\frac{\sigma - 1}{\sigma V} \right) \left(\frac{\delta - 1}{\delta v} \right)^\gamma. \tag{4.29}
\end{aligned}$$

Real wage in autarky depends on the share of intermediate goods in production γ , variable costs and the elasticities of substitution. The higher γ , the more sensitive real wage is to changes in the intermediate sectors.

In a frictionless world, $t_{ij} = t_{ji} = 1$. Rewrite the labour market equilibrium conditions (4.26) and (4.27) for two countries i and j , and also note that price indexes are identical across countries:

$$\frac{w_i}{w_j} = \frac{L_i^M}{L_j^M} = \frac{L_i^C}{L_j^C}. \tag{4.30}$$

In a frictionless world, the relative real wages (which equal to relative nominal

¹⁰⁶In a symmetric world where $w_i \bar{L}_i = w_j \bar{L}_j$ for all pairs, $\sum_j \pi_{ij} = 1$.

¹⁰⁷From (4.21)-(4.23) we can calculate that $\frac{\alpha_i \gamma}{1 - \alpha_i \gamma} = \gamma$.

wages) are the relative size of both sectors (in labour) between country i and j .

e) Gains from Trade

In this section I show the welfare implications of the model. To start with, take income share country i spent on its own goods:

$$\begin{aligned}\pi_{ii}^M &= \left(\frac{q_i}{Q_i}\right)^{1-\delta} \\ \pi_{ii}^C &= \left(\frac{p_i}{P_i}\right)^{1-\sigma}.\end{aligned}\tag{4.31}$$

Using these equations and the equilibrium prices, we get an expression of real wage (w_i/P_i) as a function of i 's shares of purchases from home:

$$\frac{w_i}{P_i} = \left(\frac{1}{\pi_{ii}^M}\right)^{\frac{\gamma}{\delta-1}} \left(\frac{1}{\pi_{ii}^C}\right)^{\frac{1}{\sigma-1}} w_i^A,\tag{4.32}$$

where w_i^A is the real wage in autarky. In autarky, $\pi_{ii}^M = \pi_{ii}^C = 1$, equation (4.32) reduces to w_i^A . It is clear that when country i trades more in either intermediate or final goods, there are gains from trade. Also, given import shares, trade gains are greater the higher γ and the lower elasticities of substitution.

4.3.4 Gravity Equations and Value-Added (VAX) Ratios

In this section I present the gravity equations derived from the model, and discuss its link to the value-added ratio presented in Johnson and Noguera (2012).

The gravity equations are derived following a six-step derivation, based on Baldwin and Taglioni (2006) in demonstrating the A-vW gravity equation.¹⁰⁸ First, I present gravity predictions for bilateral intermediate goods trade in terms of gross outputs (Y) and country GDP (I):

$$\begin{aligned}T_{ij}^M &= \left(\frac{\tau_i + \gamma - 1}{\gamma}\right) (1 - \tau_j) \frac{Y_i Y_j}{Y^W} \left(\frac{t_{ij}}{\Pi_i^M Q_j}\right)^{1-\delta} \\ &= \left(\frac{\tau_i + \gamma - 1}{\tau_i \gamma}\right) \left(\frac{1 - \tau_j}{\tau_j}\right) \frac{I_i I_j}{Y^W} \left(\frac{t_{ij}}{\Pi_i^M Q_j}\right)^{1-\delta},\end{aligned}\tag{4.33}$$

where $\Pi_i^M \equiv \left(\sum_j \left(\frac{t_{ij}}{Q_j}\right)^{1-\delta} \frac{E_j^M}{Y^W}\right)^{1/(1-\delta)}$.¹⁰⁹ The standard prediction that richer

¹⁰⁸The derivation is presented in Appendix 4.A in detail.

¹⁰⁹Note that labour share of income is exogenous depending on γ . Here we assume γ is constant

countries trade mode still hold. Bilateral trade in intermediate goods is increasing in τ_i but decreasing in τ_j .

Similarly, bilateral final goods trade in terms of gross outputs and country GDPs are:

$$\begin{aligned} T_{ij}^C &= \left(\frac{1 - \tau_i}{\gamma} \right) \tau_j \frac{Y_i Y_j}{Y^W} \left(\frac{t_{ij}}{\Pi_i^C P_j} \right)^{1-\sigma} \\ &= \left(\frac{1 - \tau_i}{\tau_i \gamma} \right) \frac{I_i I_j}{Y^W} \left(\frac{t_{ij}}{\Pi_i^C P_j} \right)^{1-\sigma}, \end{aligned} \quad (4.34)$$

where $\Pi_i^C \equiv \left(\sum_j \left(\frac{t_{ij}}{P_j} \right)^{1-\sigma} \frac{E_j^C}{Y^W} \right)^{1/(1-\sigma)}$. The second line of the equation shows trade in final goods is decreasing in τ_i . The equation also shows that GDP of the importer country remains a good proxy for predicting trade in final goods.

The VAX ratio for a country captures the domestic content of exports. It is defined by Johnson and Noguera (2012) as the ratio between value-added exports to gross exports. Here I focus on the bilateral VAX ratio:

$$VAX_{ij} \equiv \frac{va_{ij}}{T_{ij}},$$

where va_{ij} is the value-added generated by country i that is absorbed in country j , and T_{ij} is the gross trade volume. VAX ratio is the proportion of actual domestic content of exports, with $VAX_{ij} < 1$. In the model, value-added ratios in each sectors equal to labour shares of income: one for intermediate sector and $(1 - \gamma)$ for final goods sector. The VAX ratio can be derived:

$$\begin{aligned} VAX_{ij} &= \frac{T_{ij}^M + (1 - \gamma) T_{ij}^C}{T_{ij}^M + T_{ij}^C} \\ &= 1 - \gamma \left(\frac{T_{ij}^M}{T_{ij}^C} + 1 \right)^{-1}. \end{aligned} \quad (4.35)$$

The model predicts that the VAX ratio is increasing with the relative trade flow T_{ij}^M/T_{ij}^C and decreasing in γ . The reason is intermediate goods sector generates higher value added by definition. Also, T_{ij}^M/T_{ij}^C can be shown using (4.33)-(4.34):

$$\frac{T_{ij}^M}{T_{ij}^C} = \left[\left(\frac{\gamma}{1 - \tau_i} - 1 \right) \left(\frac{1}{\tau_j} - 1 \right) \right] (t_{ij})^{\sigma-\delta} (\Pi_i^C P_j)^{1-\sigma} (\Pi_i^M Q_j)^{1-\delta}. \quad (4.36)$$

and discuss the effects of the labour share of income only.

In a frictionless world, $t_{ij} = 1$ and $(\Pi_i^C P_j)^{1-\sigma} (\Pi_i^M Q_j)^{1-\delta} = 1$, and T_{ij}^M/T_{ij}^C reduces to the term in brackets. The bilateral VAX ratio, denoted as VAX_{ij}^F , becomes:

$$VAX_{ij}^F = 1 - \gamma \left[\left(\frac{\gamma}{1 - \tau_i} - 1 \right) \left(\frac{1}{\tau_j} - 1 \right) + 1 \right]^{-1}. \quad (4.37)$$

Again we see the opposite effects τ_i and τ_j have on the ratio.

The key result of the analysis is that the weighted averages of labour share of income in the exporting country and the importing country have different impacts on bilateral trade flows as well as the bilateral value-added to gross trade ratios. Intuitively, for the exporter, an increase in the weighted average of labour share of income leads to a larger intermediate sector, which contributes to more exports of intermediate goods. For the importer, on the other hand, a higher weighted average of labour share of income implies a lower expenditure on intermediate inputs, resulting in less imports of intermediate goods.

4.4 Concluding Remarks

This paper asks whether trade in intermediate goods matters to the performance of the standard gravity models. When countries are involved in any production sharing in which production process goes through more than two countries, there is a further hidden trade structure underlying the gross trade flows.

It is common knowledge that the gravity models often overestimate bilateral trade flows. I first show in a simple accounting framework that it is the use of (domestic or imported) intermediate goods rather than trade in intermediate goods that results in the missing trade. Put differently, with the presence of intermediate goods a gravity model based on country outputs would overestimate gross trade flows and trade in intermediate goods actually helps shorten the gap between actual and predicted trade volume.

I then introduce the use of intermediate goods in production into a general equilibrium model with complete specialisation and monopolistic competition in both intermediate and final goods sectors. The first model result shows gains from trade for trade in both types of goods. Next I derive the corresponding gravity equations for both trade in intermediate and final goods. The main contribution of the paper is to identify what drives the differences between trade in intermediate goods and final goods from a theoretical point of view. The model results suggest that labour shares of income from the importing and exporting countries enter the gravity equations with the opposite signs. The results speak up to the argument that using economic mass variables such as GDPs in gravity equations may not

well capture the underlying trade structure and leads to a bias in the estimates.¹¹⁰ Also this result is particularly relevant when exploring cross-sectoral comparisons in trade elasticities.

How can the results be tested empirically? One potential starting point would be estimating a baseline gravity model with country GDPs as proxies and then examining whether adding labour shares of income improves the performance of the model.

¹¹⁰Therefore the paper does not relate to gravity models using fixed effects instead of economic mass variables as proxies.

4.A The Derivation of Gravity Equations

The bilateral trade flows of intermediate goods can be derived in six steps.

Step 1: Supply equals demand. The value of trade flow in intermediate goods from i to j should equal to the share country i has in expenditure of j .

$$\begin{aligned} q_{ij} T_{ij}^M &= \pi_{ij}^M E_j^M \\ &= \pi_{ij}^M (1 - \tau_j) Y_j, \end{aligned} \quad (\text{A-1})$$

where the second equation comes from the definition in Table 4.1.

Step 2: π_{ij}^M follows a CES demand structure.

$$\pi_{ij}^M = \left(\frac{q_{ij}}{Q_j} \right)^{1-\delta}. \quad (\text{A-2})$$

Step 3: Adding trade costs.

$$q_{ij} = t_{ij} q_i. \quad (\text{A-3})$$

Step 4: Aggregating across varieties, we can get the total intermediate trade flow from i to j .

$$\begin{aligned} T_{ij}^M &= n_i \pi_{ij}^M E_j^M \\ &= n_i \left(\frac{t_{ij} q_i}{Q_j} \right)^{1-\delta} (1 - \tau_j) Y_j. \end{aligned} \quad (\text{A-4})$$

Step 5: Market clearing condition holds.

$$\begin{aligned} Y_i^M &= \sum_j T_{ij}^M \\ &= n_i q_i^{1-\delta} \sum_j \left(\frac{t_{ij}}{Q_j} \right)^{1-\delta} (1 - \tau_j) Y_j, \end{aligned} \quad (\text{A-5})$$

where the second equation follows from (A-4). We can rewrite (A-5) as:

$$\begin{aligned} n_i q_i^{1-\delta} &= \frac{Y_i^M / Y^W}{(\Pi_i^M)^{1-\delta}} \\ &= \left(\frac{\tau_i + \gamma - 1}{\gamma} \right) \frac{Y_i / Y^W}{(\Pi_i^M)^{1-\delta}}, \end{aligned} \quad (\text{A-6})$$

where $\Pi_i^M \equiv \left(\sum_j \left(\frac{t_{ij}}{Q_j} \right)^{1-\delta} \frac{E_j^M}{Y^W} \right)^{1/(1-\delta)}$.

Step 6: A gravity equation for intermediate trade flow can now be derived by combining (A-4) and (A-6):

$$T_{ij}^M = \left(\frac{\tau_i + \gamma - 1}{\gamma} \right) (1 - \tau_j) \frac{Y_i Y_j}{Y^W} \left(\frac{t_{ij}}{\Pi_i^M Q_j} \right)^{1-\delta}. \quad (\text{A-7})$$

Using (4.21) and (4.22) in the main text we can also rewrite the gravity equation in terms of country GDPs:

$$T_{ij}^M = \left(\frac{\tau_i + \gamma - 1}{\tau_i \gamma} \right) \left(\frac{1 - \tau_j}{\tau_j} \right) \frac{I_i I_j}{Y^W} \left(\frac{t_{ij}}{\Pi_i^M Q_j} \right)^{1-\delta}. \quad (\text{A-8})$$

Similarly, the bilateral trade flows of final goods can be derived in the same way.

Step 1: Supply equals demand. The value of trade flow in final goods from i to j should equal to the share country i has in expenditure of j .

$$\begin{aligned} p_{ij} T_{ij}^C &= \pi_{ij}^C E_j^C \\ &= \pi_{ij}^C \tau_j Y_j. \end{aligned} \quad (\text{A-9})$$

Step 2: π_{ij}^C follows a CES demand structure.

$$\pi_{ij}^C = \left(\frac{p_{ij}}{P_j} \right)^{1-\sigma}. \quad (\text{A-10})$$

Step 3: Adding trade costs.

$$p_{ij} = t_{ij} p_i. \quad (\text{A-11})$$

Step 4: Aggregating across varieties, we can get the trade flow from i to j .

$$\begin{aligned} T_{ij}^C &= n_i \pi_{ij}^C E_j^C \\ &= n_i \left(\frac{t_{ij} p_i}{P_j} \right)^{1-\sigma} \tau_j Y_j. \end{aligned} \quad (\text{A-12})$$

Step 5: Market clearing condition holds.

$$\begin{aligned}
Y_i^C &= \sum_j T_{ij}^C \\
&= n_i p_i^{1-\sigma} \sum_j \left(\frac{t_{ij}}{P_j} \right)^{1-\sigma} \tau_j Y_j,
\end{aligned} \tag{A-13}$$

Rewriting it gives:

$$\begin{aligned}
n_i p_i^{1-\sigma} &= \frac{Y_i^C / Y^W}{(\Pi_i^C)^{1-\sigma}} \\
&= \left(\frac{1 - \tau_i}{\gamma} \right) \frac{Y_i / Y^W}{(\Pi_i^C)^{1-\sigma}},
\end{aligned} \tag{A-14}$$

where $\Pi_i^C \equiv \left(\sum_j \left(\frac{t_{ij}}{P_j} \right)^{1-\sigma} \frac{E_j^C}{Y^W} \right)^{1/(1-\sigma)}$.

Step 6: A gravity equation for intermediate trade flow can now be derived:

$$\begin{aligned}
T_{ij}^C &= \left(\frac{1 - \tau_i}{\gamma} \right) (\tau_j) \frac{Y_i Y_j}{Y^W} \left(\frac{t_{ij}}{\Pi_i^C P_j} \right)^{1-\sigma} \\
&= \left(\frac{1 - \tau_i}{\tau_i \gamma} \right) \frac{I_i I_j}{Y^W} \left(\frac{t_{ij}}{\Pi_i^C P_j} \right)^{1-\sigma}.
\end{aligned} \tag{A-15}$$

Chapter 5

Conclusions and Future Research

With the rise of global production sharing, we have seen a gap between the empirical regularity and scholarly work in the literature. This thesis explores the implications of trade in intermediate goods for the aggregated degree of exchange rate pass-through, firms' invoicing currency choice and the gravity predictions in each of the three chapters. Incorporating trade in intermediate goods into several strands of literature in international economics allows for a richer discussion on real world related issues such as comparing the degrees of exposure to external shocks between countries and industries during a recession. One common conjecture is that trade in intermediate goods has declined more rapidly than global trade, i.e. the bullwhip effect. Ferrantino and Taglioni (2014) show that trade in intermediate goods dropped drastically when the Global Trade Collapse started and boomed back quickly in the end of 2009. They also show a substantial regional and sectoral variation depending on the nature of the linkage.

I also find similar patterns from UK import data between the year of 2002 and 2011. Overall, during the period imports of intermediate goods grew faster than either imports of capital or consumption goods. The 2008-09 global crisis had a significant impact on imports of intermediate goods whereas imports of consumption goods were less responsive to the recession. When looking into sectoral differences (at the SITC 1-digit level), in six out of nine industries imports of intermediate goods grew faster and were more volatile than imports of consumption goods. The exceptions are food and live animals (SITC 0), beverages and tobacco (SITC 1) and miscellaneous manufactured articles (SITC 8). These findings all suggest a different nature of trade in intermediate goods as opposed to trade in final goods.

In this thesis I first introduce a back-and-forth trade structure into a two-country model to study the effects on the aggregated degree of exchange rate pass-through.

The key channel is through firms' endogenous currency choice. Chapter 2 shows that back-and-forth trade is associated with lower aggregated degrees of exchange rate pass-through. This framework offers a theoretical ground for testing the relationship between back-and-forth trade and the degree of pass-through. This is particularly relevant for examining the heterogeneity in pass-through across industries. In the UK, for example, the degree of pass-through to import prices exhibits significant heterogeneity across industries (Mumtaz, Oomen, and Wang, 2006). In future work, I plan to study whether this variation can be attributed to different currency behaviours or frequencies of price adjustments across industries.

Another extension I plan to do next is to follow Gopinath, Itskhoki and Rigobon (2010) to examine how firms' price adjustments differ depending on the currencies in which prices are set. They use US data and actually most of US exports as well as imports are priced in US dollars. Empirical evidence from the UK, a small open economy, will therefore add insights to the link between invoicing currency and the frequencies of price adjustments. In my view, both currency choice and price setting are crucial to fully understand the estimations of short-run and long-run pass-through. It is therefore important to examine the interactions between these two channels through which domestic prices and inflation rates respond to exchange rate shocks.

There are large differences in invoicing currency choice across firms, even across firms that export the same product to the same country at the same time. The explanation has to come from firm characteristics. The stylised facts documented in Chapter 3 are completely new and I view this as the main contribution of the thesis. In the paper I consider firm sizes in terms of export shares and firm experience in terms of the years of exporting. These proxies are obtained from the export dataset and therefore they somehow relate to firms' exporting behaviour. In future work, I plan to incorporate the FAME (Financial Analysis Made Easy) dataset which contains information on U.K. company profiles such as operating revenues, numbers of employees and financial strength indicators. In doing so it will shed light on the role other firm characteristics play in determining currency choice. For instance, it is possible to identify intra-firm trade for multinationals and examine its impact on currency denomination.

Chapter 3 also speaks to the hedging literature. In the paper, I introduce exporters' dependence on imported inputs as an alternative determinant of their invoicing currency choice. Firms more dependent on imported are more likely to choose the same currency used for their imported inputs to price their exports. Although the intuition of the theoretical mechanism is rather subtle, this theoretical prediction is consistent with the idea of a natural hedging and supported by the data. Do firms actually pursue a natural hedging or simply rely on financial

instruments? How do the practices differ geographically? My paper opens up the possibility to disentangle firms' financial operations from natural hedging under the considerations of exchange rate uncertainty.

Another aspect Chapter 3 does not consider is the trend of currency choice over time. Although I do not observe much variation in the general patterns of invoicing currency when comparing the 2010 and 2011 UK data, it is desirable to examine a longer time span to further understand the determinants of invoicing currency choice. One possible explanation for a stable invoicing currency pattern is that trading partners may sign a short-term to medium-term contract with each other specifying an invoicing currency in which prices will be quoted.

In Chapter 2 and 3 an implicit assumption based on monopolistic competition is that exporters do *choose* their own invoicing currencies. There has been empirical evidence from Swedish survey data that a large proportion of exporters do set their own currency (Friberg and Wilander, 2008). However in reality this may be industry or location specific and in some cases exporters settle a currency through bargaining with the importers. Questionnaire studies would thus be desirable to explore the nature of currency setting in more depth.

Chapter 4 suggests a link between gravity equations and the labour shares of income. The model yields some testable hypotheses to take labour shares of income into account. The results, however, may be specific to models with monopolistic competition and CES demand structures. One potential direction for future work is to study whether similar results can also be obtained from other trade models.

Another related topic of interest is the estimation of trade elasticities. There has been studies showing an increase in trade elasticities with respect to global income due to the rise of global intermediate input linkages (Escaith, Lindenberg and Miroudot, 2010). Is there a variation across industries? Can accounting for labour shares of income help improve the estimation of cross-sectoral trade elasticities? These are questions to be answered.

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